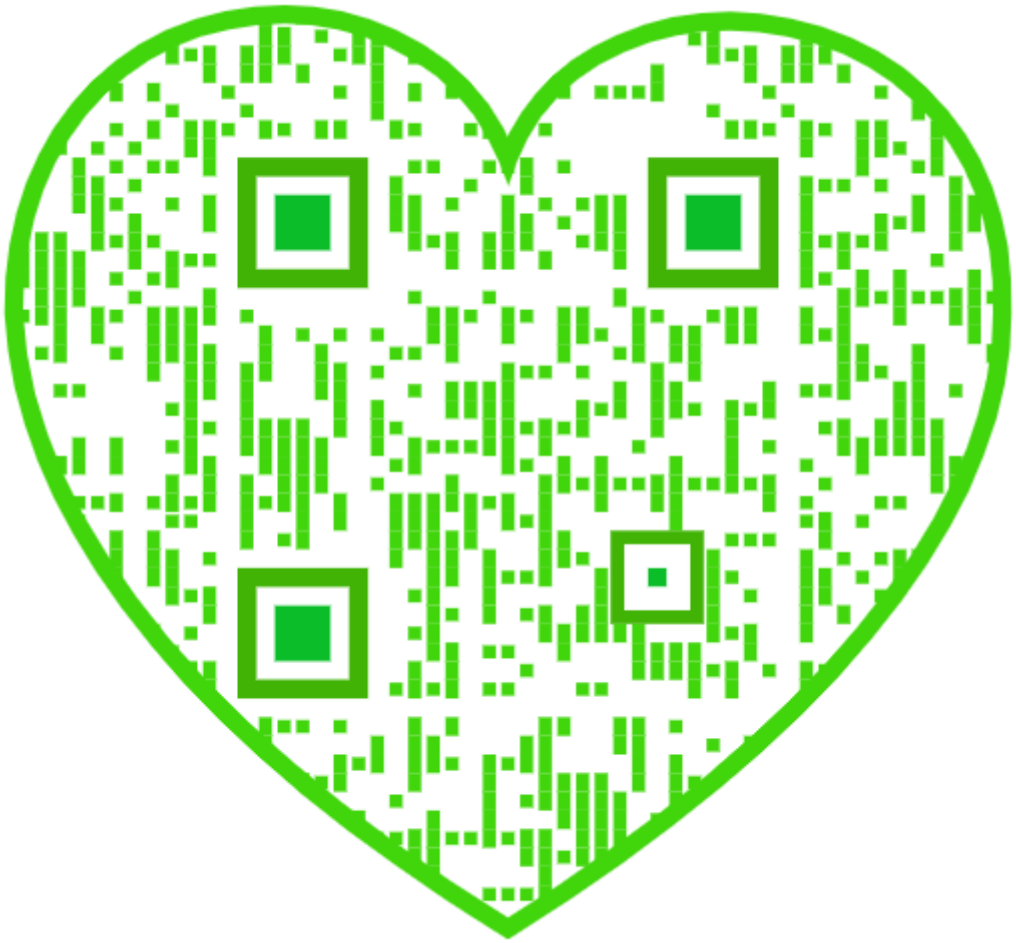

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FARM IMPLEMENTS,

AND THE

PRINCIPLES OF THEIR CONSTRUCTION AND USE;

AN

ELEMENTARY AND FAMILIAR TREATISE

ON MECHANICS,

AND ON NATURAL PHILOSOPHY GENERALLY, AS APPLIED TO THE ORDINARY PRACTICES OF AGRICULTURE.

WITH 200 ENGRAVED ILLUSTRATIONS.

BY JOHN J. THOMAS.

"We should like to see this work printed, bound, and hung up in every workshop, tool-room, and farmer's book-shelf in the country. It gives the reason and explains the action of mechanical powers, and the forces of nature generally, with illustrations so directly drawn from the farmer's daily routine, that it gives a direct meaning and value to every point, rarely found in text-books."—*Downing's Review of the First Edition.*

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PREFACE.

THIS work, in its original form, was published in the Transactions of the New York State Agricultural Society for 1850, under the title of "AGRICULTURAL DYNAMICS," or the Science of Farm Forces. The present edition is prepared on the basis of the original essay, and is thoroughly revised and greatly enlarged, with the addition of more than double the former number of illustrations.

It comprehends those branches of Natural Philosophy known as Mechanics, Hydrodynamics, Pneumatics, and Heat, in their more common application to the practices of modern improved farming; and, so far as practicable, technical words and phrases have been avoided, and the whole rendered simple and intelligible to ordinary readers.

The leading principles have been derived from the existing stock of knowledge; but no treatise on these subjects, as specially applied to agriculture, having before appeared, the various examples of the application of those principles to the structure and use of farm implements, and to the farmer's daily routine, are mostly original.

For the purpose of adapting the work to schools, wherever it may be desirable, it is divided into sections, each of sufficient length for a single recitation.

CONTENTS.

PART I.

MECHANICS.

CHAPTER I.

INTRODUCTION.

Page
Benefits of Mechanical Knowledge 13

CHAPTER II.

GENERAL PRINCIPLES OF MECHANICS.

SECTION I.

General Properties of Matter 18
Divisibility 18
Impenetrability 20
Indestructibility 20
Inertia 21

SECTION II.

Momentum, or Inertia of moving Bodies 24
The Fly-wheel 27
Application of Fly-wheel in churning and cutting Straw 28
Estimating the Quantity of Momentum 30

SECTION III.

Compound Motion 31
Centrifugal Force 34

CHAPTER III.

ATTRACTION.

SECTION I.

Gravitation 35
Measuring Velocity of falling Bodies—Atwood's Machine 38

SECTION II.

Page
Cohesion 42
Strength of Materials 43
Capillary Attraction 47
Ascent of Sap 49

SECTION III.

Centre of Gravity 50
Line of Direction 52

CHAPTER IV.

SIMPLE MACHINES, OR MECHANICAL POWF

SECTION I.

Advantages of Machines 60
Law of Virtual Velocities 61

SECTION II.

The Lever 63

SECTION III.

Estimating the Power of Levers 67
Combination of Levers 70
Weighing Machine 71
Machines for extracting Stumps 72

SECTION IV.

Wheel and Axle 75
Mole-plow 78
Band and Cog Wheels 79
Form of Teeth or Cogs 80

SECTION V.

The Pulley 83

SECTION VI.

The Inclined Plane 86
Ascent in Roads 87
Form and Materials for Roads 90
Importance of good Roads 92

SECTION VII.

The Wedge 93
The Screw 94

CHAPTER V.

APPLICATION OF MECHANICAL PRINCIPLES IN THE STRUCTURE OF THE PARTS OF IMPLEMENTS AND MACHINES.....Page 96

CHAPTER VI.

FRICTION.

SECTION I.

Rolling Friction 103
Nature of Friction 104
Estimating the Amount of Friction 104

SECTION II.

Results with the Dynamometer 107
Width of Wheels 109
Velocity as affecting Friction 110
Friction at the Axle 111
Friction Wheels 112

SECTION III.

Lubricating Substances 113
Advantages of Friction 115

SECTION IV.

Principles of Draught..... 117
Combined Draught of Animals 120

SECTION V.

Construction and use of the Dynamometer..... 122
Self-recording Dynamometer 125
Dynamometer for Rotary Motion 126

CHAPTER VII.

CONSTRUCTION AND USE OF FARM IMPLEMENTS AND MACHINES.

SECTION I.

Plows and Plowing 130
Trench and Subsoil Plowing..... 134
The double Mould-board Trench Plow..... 135
The Subsoil Plow..... 136
Fowler's Draining Plow..... 136
The Paring Plow—The Gang Plow..... 140

SECTION II.

Page
Pulverizers 141
The Harrow 141
Cultivators 143
Clod-crushers 146

SECTION III.

Sowing-machines 148
Horse Rakes 152
Mowing and Reaping Machines 156

SECTION IV.

Knee-joint Power 159
Endless-chain Powers 164

SECTION V.

Application of Labor 167

SECTION VI.

Models of Machines 173

PART II.

HYDRODYNAMICS.

CHAPTER I.

HYDROSTATICS.

SECTION I.

Upward Pressure 176
Measurement of Pressure at different Heights 178
Determining the Strength of Pipes 179
Springs and Artesian Wells 179

SECTION II.

Determining Pressure on Surfaces 180
Hydrostatic Bellows 183
Hydrostatic Press 184

SECTION III.

Specific Gravities 187

CHAPTER II.

HYDRAULICS.

SECTION I.

Velocity of falling Water 189
Discharge of Water through Orifices and Pipes 190

SECTION II.

Page
Velocity of Water in Ditches 192
Leveling Instruments 194

SECTION III.

HYDRAULIC MACHINES.

Archimedean Screw 196
Archimedean Root-washer 197
Pumps 198
Water-ram 200
Water-engines 202
Flash-wheel 203

SECTION IV.

WAVES.

Nature of Waves 204
The Water not progressive 205
Breadth and Velocity of Waves 206
Preventing the Inroads of Waves 208

SECTION V.

Contents of Cisterns 210
Rule for determining the Contents 211
Determining their Size 212

PART III.

PNEUMATICS.

CHAPTER I.

PRESSURE OF AIR.

Height and Weight of the Atmosphere 213
The Barometer 216
The Syphon 218

CHAPTER II.

MOTION OF AIR.

SECTION I.

Winds—Force of Wind 221
Wind-mills for Farms 223
Causes of Wind 227

SECTION II.

Page
Chimney Currents 227
Construction of Chimneys 228
Chimney-caps 229
Ventilation 232

PART IV.

HEAT.

CHAPTER I.

CONDUCTION OF HEAT.

SECTION I.

Conducting Power of Bodies 235
Utility of this Principle 236
Conducting Power of Liquids 237

SECTION II.

Expansion by Heat 238
The Steam-engine 241
Exception to Expansion by Heat 246

SECTION III.

Latent Heat 248
Advantages of Latent Heat—Latent Heat of Steam 249
Green and dry Wood for Fuel 250

CHAPTER II.

Radiation of Heat 253
Dew and Frost 255
Frost in Valleys—Remarkable Effects of Heat on Water 256

APPENDIX.

Apparatus for Experiments 259
Tables of Specific Gravities 263
Weight of a cubic Foot of various Substances 264
Discharge of Water through Pipes 264
Velocity of Water in Pipes 265
Rule for the Discharge of Water 266

FARM IMPLEMENTS,

AND THE

PRINCIPLES OF THEIR CONSTRUCTION AND USE.

PART I.

MECHANICS.

CHAPTER I.

INTRODUCTION.

No farm, even of moderate size, can be well furnished without a large number of machines and implements. Scarcely any labor is performed without their assistance, from the simple operations of hoeing and spading, to the more complex work of turning the sod and driving the thrashing-machine. It becomes, therefore, a matter of vital importance to the farmer to be able to construct the best, or to select the best already constructed, and to apply the forces required for the use of such machines to the best possible advantage.

A great loss occurs frequently from the want of a correct knowledge of mechanical principles. The strength of laborers is often badly applied by the use of unsuitable tools, and that of teams is partly lost by being ill adjusted for the best line of draught; as, for

example, by a bad attachment to the plow for forcing its wedge-like form most effectively through the soil. We may perhaps see but few instances of so great a blunder as the man committed who fastened his smaller horse to the shorter end of the whipple-tree, to balance the large horse at the longer end; or of the other man, who, when riding on horseback to mill, atop of his bag of grain, concluded to relieve the animal by dismounting, shouldering the bag himself, and then remounting; yet cases are not uncommon where other operations are performed to almost as great a disadvantage, and which, to a person well versed in the science of mechanics, would appear nearly as strange and absurd.

The improvement of farm machines and tools within the last fifty years has probably enabled the farmer to effect twice as much work with the same force of horses and men. Plows turn up the soil deeper, more evenly and perfectly, and with greater ease of draught; hoes and spades have become lighter and more efficient; grain, instead of being beaten out by the slow and laborious work of the flail, is now showered in torrents from the thrashing-machine; horse-rakes accomplish singly the work of many men using the old hand-rake; twelve to twenty acres of ripe grain are neatly cut in one day with a two-horse reaper; wheat drills, avoiding the tiresome drudgery of sowing by hand, are materially increasing the amount of the wheat crop; while a few farmers are making a large yearly saving by the application of horse-power to sawing wood, churning, driving washing-machines, and even to ditching. A celebrated English farmer has lately accom-

plished even more; for, by means of a steam-engine of six-horse power, he drives a pair of mill-stones for grinding feed, thrashes and cleans grain, elevates and bags it, pumps water for cattle, cuts straw, turns the grindstone, and drives liquid manure through pipes for irrigating his fields; and the waste steam cooks the food for his cattle and swine—all this work being performed in a first-rate manner.

Now these improvements were mainly effected through the knowledge of mechanical principles, and many of them would doubtless have been sooner achieved and better perfected if these principles had been well understood by farmers; for, constantly using the machines themselves, they could have perceived just what defects existed, and, by understanding the reasons of those defects, have been able to suggest the remedies in a better manner than the mere manufacturer. Moreover, as the introduction of what is new and valuable depends greatly upon the call for them, farmers would have been prepared to decide with more confidence and certainty upon their real merits, and thus to increase and cheapen the supply of the best, and to reject the worthless.

One great reason that farm implements are still so imperfect, is, that the farmers themselves do not fully understand what is needed, and how much may be yet accomplished. They have not enough knowledge of the principles of mechanics to qualify them for judging of the merits of new machines; and, being afraid of imposition, often reject what is really valuable, or else, being pleased with a fine appearance, are easily deceived with empty pretensions.

The implements and machines which every farmer must have who does his work well are numerous and often costly. A farm of one hundred acres requires the aid of nearly all the following: two good plows, a small plow, a subsoiler, a single and two-horse cultivator, a drill-barrow, a roller, a harrow, a fanning-mill, a straw-cutter, a root-slicer, a farm wagon with hay-rack, an ox-cart, a horse-cart, wheel-barrow, sled, shovels, spades, hoes, hay-forks and manure-forks, hand-rakes and revolving rakes, scythes and grain-cradles, grain-shovel, maul and wedges, pick, axes, wood-saw, turnip-hook, hay-knife, apple-ladders, and many other smaller conveniences. The capital for thus furnishing in the best manner all the farms in the Union has been computed to amount to five hundred millions of dollars, and as much more is estimated to be yearly paid for the labor of men and horses throughout the country at large.

To increase the effective force of labor only one fifth would, therefore, add annually one hundred millions in the aggregate to the profits of farming; while on the other hand, if we look back fifty years to the imperfect implements then in use, we may at once perceive the vast amount saved by the improvements since made; and when, especially, we notice the condition of barbarous nations, and contrast that condition with our own—the former thinly scattered in comfortless hovels through far-stretching and gloomy forests, subsisting mainly by hunting and fishing, and often suffering from hunger and cold; the latter blessed with smooth, cultivated fields, green meadows, and golden harvests, interspersed with comfortable farm-houses; with the

hum of business through populous cities, and along far-reaching lines of canals and rail-roads, and ships for foreign commerce, freighted with the productions of the soil, threading every channel and whitening every sea—when we observe this contrast, we can not fail to be struck with the convincing proof that "knowledge is power," and of the loss sustained on the one hand from its absence, and the advantages on the other of availing ourselves of its accumulated stores.

CHAPTER II.

GENERAL PRINCIPLES OF MECHANICS.

SECTION I.

GENERAL PROPERTIES OF MATTER.

HAVING briefly pointed out some of the advantages to the farmer of understanding the principles of the machines he constantly uses, we now proceed to an examination of these principles. It will be most convenient to begin with the simpler truths of the science, proceeding, as we advance, to their application in the construction of machines.

The term *matter* is applied to whatever composes those substances which we perceive with our external senses; and when we speak of a "body," we mean any thing composed of matter. Thus, wood, stone, water, and metal are matter; while the mind and its qualities are not matter. A stone, a block of wood, a bag of sand, and any other mass of matter, are termed *bodies*.

DIVISIBILITY.

Matter possesses several general properties, the examination of which is both useful and interesting. One of these is its *divisibility*, or capability of being divided into small parts, and again divided, so far as we know, without any limit. Many experiments show the great minuteness to which this division may be carried. For

example, a gold leaf may be hammered till $\frac{1}{380000}$ of an inch in thickness, or one thousand times thinner than a leaf of this book. A silver wire may be coated with gold, and then drawn out so fine that the gold coating shall become a thousand times less than the gold leaf itself. So attenuated is one of the threads of a small spider's web, that half a pound would reach round the globe. It has been found that tripoli, a mineral used in the arts, is made up of shells of exceedingly minute animals, so small that a single cubic inch contains forty thousand millions, or fifty times as many individuals as there are human beings on the face of the earth. Hundreds of animalcules (or minute animals) have been seen with a microscope in a single drop of water, without in the least degree affecting its transparency. Some of these are so small that thousands could rest, without crowding, on the point of a pin; yet these have blood-vessels, muscles, and other parts, as well as larger animals. Still more minute appears to be the division of those substances which are constantly throwing off odors or perfumes. A grain of musk will scent the air of a room for years, with particles inconceivably minute; and a bed of flowers will fill the air with their odor, as hundreds of miles of the breeze successively pass over them, with an insensibly small portion of their own weight.

But no division, however minute, ever destroys matter; every particle still retains its identity; and the largest mountains, weighing millions of tons, are made up of these innumerable particles.

IMPENETRABILITY.

Another property of matter is *impenetrability*, or the inability of two portions to occupy the same space at the same time. A nail driven into wood only crowds the particles of wood asunder. Sugar will dissolve in water, but the particles of the sugar only pass in between those of the water. Wood becomes soaked with water by its entering the pores of the wood. These pores are seen by means of a powerful microscope, and are so small that one million have been computed to exist in a space not larger than a five-cent piece.

INDESTRUCTIBILITY.

Another property is *indestructibility*. Matter is separated and changed in form from one body to another, but never destroyed. When wood is burned in the fire, it disappears; but it is found that the smoke, vapor, and ashes weigh as much as before, although in a different form. The flashing of gunpowder appears to destroy it wholly; but if all the vapors and gases are retained within a vessel, they are found to weigh as much as the original solid. Growing plants derive all their weight from the soil and air; they decay again, and form the manure for new plants; but none of their particles are lost. They furnish food for animals, or are manufactured into different substances, and, in all the changes they undergo, still retain their existence.

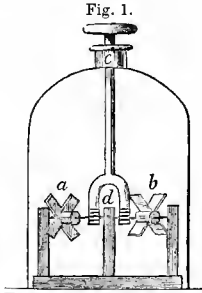
INERTIA.

There is still another and very important quality of all material bodies, called INERTIA. This term expresses their passive state—that is, that no body (not having life), when at rest, can move itself, nor, when in motion, can stop itself. A stone can not commence rolling of its own accord; a carriage can not travel on the road without being drawn; a train of cars can not commence gliding upon the rails without the power of the locomotive.

On the contrary, a body, when once set in motion, will continue in motion perpetually, unless stopped by something else. A cannon ball rolled upon the ground continues rolling till its force is gradually overcome by the resistance of the rough earth. If a polished metallic globe were driven swiftly on a level and polished metallic plane, it would continue in motion a long time and travel to a great distance; but still the extremely minute roughness of the surfaces, with the resistance of the air, would continually diminish its speed until finally stopped. A wheel made to spin on its axis continues till the friction at the axis and the impeding force of the air bring it to rest. But if the air is first removed by means of an air-pump, the motion will continue much longer. Under a glass receiver, thus exhausted, a top has been made to spin for hours, and a pendulum to vibrate for a day. The resistance of the air may be easily perceived by first striking the edge and then the broad side of a large piece of pasteboard against the air of a room. It is further shown by means of an interesting experiment

with the air-pump. Two fan-wheels, made of sheet tin, one (*a*) striking the air with its edges, and the other (*b*) with its broad faces (*Fig.* 1), are set in motion alike; *b* is soon brought to rest, while *a* continues revolving a long time. If now they are placed under the receiver of an air-pump, the air exhausted, and motion given to them alike by the rack-work *d*, they will both continue in motion during the same period.

Fig. 1.



Fans revolving in a vacuum.

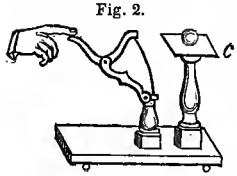
There is no machinery made by man free from the checking influence of friction and the air; and for this reason, no artificial means have ever devised a perpetual motion by mechanical force. But we are not without a proof that motion will continue without ceasing when nothing operates against it. The revolutions of the planets in their orbits furnish a sublime instance; where removed from all obstructions, these vast globes wheel round in their immense orbits, through successive centuries, and with unerring regularity, preserving undiminished the mighty force given them when first launched into the regions of space.

To set any body in motion, a *force* is requisite, and the heavier the body, the greater must be the force. A small stone is more easily thrown by the hand than a cannon ball; speed is much more easily given to a skiff than to a large and heavy vessel; but the same force which sets a body in motion is required to stop it. Thus, a wheel or a grindstone, made to revolve rapidly, would require as great an effort of the arm to stop it

suddenly as to give it sudden motion. An unusual exertion of the team is required in starting a loaded wagon; but when once on its way, it would require the same effort of the horses to stop it as to *back* it when at rest.

The force of inertia is finely exhibited by means of a little instrument called the *inertia apparatus* (*Fig.* 2). A marble or small ball is placed on a card (*c*) resting on a concave stand. A spring snap is then made to strike the card, throwing it to a distance, but leaving the ball upon the hollow end of the stand. The same experiment may be easily performed by placing a very small apple or other solid on a card, the whole resting on a common sand-box, or even the hollow of the hand. A sudden snap with the finger will throw the card away, while the apple will drop into the cavity. The following experiment is still more striking: Procure a thread just strong enough to bear three pounds, and hang upon it a weight of two pounds and a half. Another half pound would break it. Now tie another thread, strong enough to bear one pound, to the lower hook of the weight. If the lower thread be pulled *gradually*, the *upper* thread will of course break; but if it be pulled with a *jerk*, the *lower* thread will break. If the jerk be very sudden, the lower string will break, even if it be considerably

Fig. 2.



Inertia Apparatus.

Fig. 3.

stronger than the upper, the *inertia* of the weight requiring a great force to overcome it suddenly. The threads used in this experiment may be easily had of any desired strength by taking the finest sewing cotton, and doubling to any required extent.

This experiment shows the reason why a horse, when he suddenly starts with a loaded wagon, is in danger of breaking the harness; and why a heavier weight may be lifted with a windlass or pulley having a weak rope, if the strain is gradual and not sudden. For the same reason, glass vessels full of water are sometimes broken when hastily lifted by the handle. When a bullet is fired through a pane of glass, the inertia retains the surrounding glass in its place during the moment the ball is passing, and a round hole only is made; while a body moving more slowly, and pressing the glass for a longer space of time, fractures the whole pane.

SECTION II.

MOMENTUM.

The force which a moving body has to continue onward is called its *momentum;* it is, in fact, the *inertia of a moving body.* When a force is first applied to any heavy body, it moves slowly; but the little momentum it thus acquires, added to the continued force, increases the velocity. This increase of velocity is of course attended with increased momentum, which again, added to the acting force, still further quickens the speed. For this reason, when a steam-boat leaves the pier, and its paddle-wheels commence tearing

through the water, the motion, at first slow, is constantly accelerated till the increasing resistance of the water to the moving mass becomes equal to the strength of the engine and the momentum.* Were it not for the momentum of moving bodies (inertia existing), no speed ever could be given to any heavy body, as a carriage, boat, or train of cars.

The chief danger in fast riding, or fast traveling of any kind, is from the momentum given to the traveler. If a rail-way passenger should step from a car when in full motion, he would strike the earth with the same velocity as that of the train; or if the train at thirty miles an hour should be instantly stopped, the passengers would be pitched forward with a swiftness equal to thirty miles an hour. When a horse suddenly stops, the momentum of the rider tends to throw him over the horse's head. When a wagon strikes an obstruction, the driver falls forward. A case in court was once decided against the plaintiff, who claimed that the defendant had driven against his wagon with such force as to throw the plaintiff to a great distance; but the fact was shown that by such momentum he himself must have been driving furiously, and not the defendant, and he lost his suit.

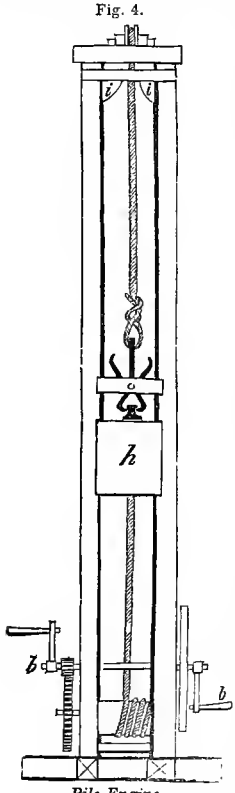
An African traveler once succeeded in saving his life by a ready knowledge of this principle. He was closely pursued by a tiger, and when near a precipice, watching his opportunity, he threw his coat and hat

* In ordinary practice, this is not strictly correct, as *friction* will make some difference. This influence will be more particularly considered on a subsequent page. Its omission here does not at all alter the *principle* under consideration.

on a bush, and jumped one side, when the animal, leaping swiftly on the concealed bush, was carried by momentum over the precipice.

As a large or heavy body possesses greater momentum than a small or light one, so any body moving with great speed possesses more than one moving slowly; for instance, the momentum of a rifle ball is so great as to carry it through a thick plank, while, if thrown slowly, it would scarcely indent it.

Fig. 4.



Pile Engine.

This property of bodies is applied with great advantage to many practical purposes. The momentum of the hammer drives the nail into the wood; for the mere pressure of its weight would not do it, if it were a hundred times as heavy. Wedges are driven by employing the same kind of power.

On a larger scale, the pile-engine operates in a similar manner. The ram or weight, *h* (*Fig.* 4), is slowly lifted by means of a pulley and wheel-work, worked by the handles or cranks, *b b*, until the arms of the tongs which hold the ram are compressed in the cheeks, *i i*, when it suddenly falls with prodigious force on the pile or post to be driven. In this way long posts of

great size are forced into the mud of swamps and river bottoms, where other means would fail. When a steam-engine is used for lifting the ram, the work is more rapidly performed.

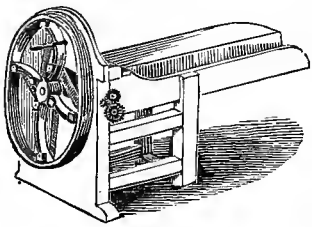
An interesting example of the use and efficiency of momentum is furnished by the *water-ram*, a machine for raising water, described on a subsequent page.

THE FLY-WHEEL.

The *fly-wheel*, a large and heavy wheel used to regulate the motion of machinery, derives its value from the power of inertia, or momentum, which prevents the machine from stopping suddenly when it meets with any unusual obstruction. In the common thrashing-machine, it has been found that a heavy cylinder, by acting as a fly-wheel, renders the motion steadier, and less liable to become impeded by large sheaves of grain. An ignorance of this principle has sometimes proved a serious inconvenience. A farmer, having occasion to raise a large quantity of water, erected a horse-pump; but at every stroke of the pump the animal was suddenly thrown loosely forward, and again jerked backward, as the piston fell lightly and rose heavily. A fly-wheel attached to the machinery would have prevented this unpleasant jerking, and have enabled the horse, in consequence, to accomplish more work. In the pile-driving engine, where a great weight is suddenly thrown loose from a height, the horses would be pitched forward when suddenly relieved of this load, but for the regulation of a fly-wheel, the motion of which is not quickly changed, neither from fast to slow nor from slow to fast.

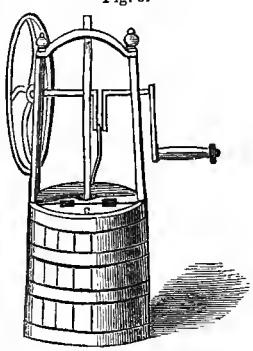
Where there is a rapid succession of forces required in practice, the fly-wheel is usually of great advantage. Hence its use in all revolving straw-cutters, where the knives make quickly-repeated strokes (*Fig.* 5). More recently it has been applied to the dasher-churn (*Fig.* 6), where the rapid upright strokes are so well known to be very fatiguing for the amount of force applied.

Fig. 5.



Straw-cutter with fly-wheel.

Fig. 6.



Churn with a fly-wheel, for equalizing the motion.

By thus regulating motion, the fly-wheel frequently enables an irregular force to accomplish work which otherwise it could not perform. Thus a man may exert a force equal to raising a hundred pounds, yet, when he turns a crank, there is one part of the revolution where he works to great disadvantage, and where his utmost force will not balance forty pounds. Hence, if the work is heavy, he may not be able to turn the crank, nor to do any work at all. If, however, a fly-wheel be applied, by gathering force at the most favorable part of the turning, it carries the crank through the other part.

An error is sometimes committed by supposing the fly-wheel actually creates power, for as much force is

required to give it momentum as it afterward imparts to the machine; it consequently only accumulates and regulates power.

A curious example of the effect of momentum is shown in the failure and success of two different modes of constructing wire fences with very slender wires for the boundaries of pastures. The unsuccessful mode consisted of tightly-stretched wires between solid posts not more than twelve to twenty feet apart. A side strain of only a few inches was enough to snap the wires; consequently, a bullock plunging blindly against them could not be quickly enough checked in his momentum, and such fences were therefore nearly useless without stronger wire. The successful mode was to stretch the wires well between strong and deeply-set posts some hundreds of feet apart, the intervening space being kept even by upright bars, but not posts. When an animal accidentally struck this fence, the great length permitted it to yield sidewise far enough to expend the momentum without rupture, when its elasticity at once threw it back to its former place.

On rough roads, the force of inertia causes a severe strain to a loaded wagon when it strikes a stone. The horses are chafed, the wagon and harness endangered, and the load jarred from its place. This inconvenience is avoided in part by placing the box upon springs, which, by yielding to the blow, gradually lessen the effects of the shock. For carts and slowly-moving lumber-wagons their advantages are considerable, but much greater as the velocity and momentum increase. Even on so smooth a surface as a rail-road, it was found, by experiments made some years ago, that when

the machinery of a locomotive was placed upon springs, it would endure the wear and tear of use four times as long as without them.

For this reason, a ton of stone, brick, or of sand is more severe for a team than a ton of wool or hay, which possesses considerable elasticity.

ESTIMATING THE QUANTITY OF MOMENTUM.

The *quantity* of momentum is estimated by the velocity and weight of the body taken together. Thus a ball of two pounds' weight moves with twice the force of a one-pound ball, the speed being equal; a ten-pound ball with ten times the force, and so on. A body moving at the rate of two feet per second possesses twice the momentum of another of equal size with a velocity of only one foot per second. A musket ball, weighing one ounce, flying with fifty times the speed of a cannon ball, weighing fifty ounces, would strike any object with equal force; or, if they should meet each other from opposite directions, the momentum of both would be mutually destroyed, and they would drop to the earth.

Where the mass is very great, even if the motion is slow, the momentum is enormous. A large ship floating near a pier wall may approach it with so small a velocity as to be scarcely perceptible, and yet the force would be enough to crush a small boat. When great weight and speed are combined, as in a rail-way locomotive, the force is almost irresistible. This circumstance often insures the safety of the passengers; for as nothing is capable of instantly overcoming so powerful a momentum, when accidents occur the speed is

more gradually slackened, and the passengers are not pitched suddenly forward. A light wagon, rapidly driven, possessing but little comparative force, is more suddenly arrested, and the danger is greater.

When two bodies meet from opposite directions, each sustains a shock equal to the united forces of both. Two men accidentally striking, even if walking moderately, receive each a severe blow; that is, if each were walking three miles an hour, the shock would be the same as if one at rest were struck by the other with a velocity of six miles an hour. This principle accounts for the destructive effects of two ships running foul of each other at sea, or of the collision of two opposite trains on a rail-road.

The preceding principles show that a sledge, maul, or ax will always strike more effective blows when made heavier, if not rendered unwieldy.

SECTION III.

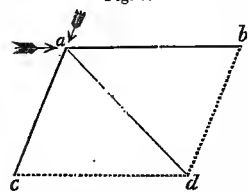
COMPOUND MOTION.

It often happens that two or more forces act on the same body at the same time. If they all act in the same direction, the effect will be equal to the sum of the forces taken together; but if they act in opposite directions, the forces will tend to destroy each other. If two equal forces act in contrary directions, they will be completely neutralized, and no motion will be produced. Thus, as an example of these forces—a bird flying at the rate of forty miles an hour, *with* a wind blowing forty miles an hour, will be driven onward by these two combined forces eighty miles an hour; but

if it undertake to fly against such a wind, it will not advance at all, but remain stationary. A similar result will take place if a steam-boat, having a speed of ten miles an hour, should first run down a river with a current of equal velocity, and then upward against the current; in the first case it would move twenty miles an hour, and in the latter it would not move at all.

Where forces act neither in the same nor in opposite directions, but obliquely, the result is found in the following manner: If a ball, placed at the point *a* (*Fig.* 7), be struck by two different forces at the same moment, in the direction shown by the two arrows, and if one force be just sufficient to carry it from *a* to *c*, and the other to carry it from *a* to *b*, then it will move intermediate between the two, in the direction of the diagonal of the parallelogram *a d*, and to a distance just equal to the length of this diagonal or cross-diameter.

Fig. 7.



When the forces act very nearly together, the parallelogram of the forces will be very narrow and quite long, with a long diagonal (*Fig.* 8); but if they act on nearly opposite sides of the ball, they will very nearly neutralize each other, and the diagonal or result will be very short, showing that the motion given to the ball will be very small (*Fig.* 9.)

Fig. 8.

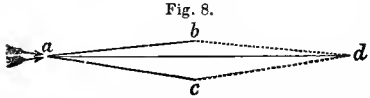
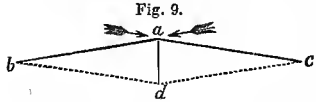


Fig. 9.



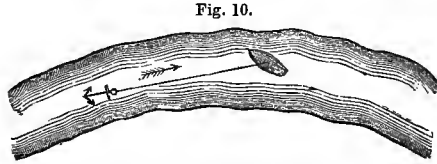
These examples show the importance of having

teams attached to a plow or to a wagon very nearly in a straight line with the draught, or else a part of the force will be lost; and also the importance, when several animals are drawing together, of their working as nearly as possible in the same straight line. For, the more such forces deviate from a right line, the more they will tend to destroy or neutralize each other.

A familiar example of the result of two oblique forces is furnished when a boat is rowed across a river. If the river has no current, the boat will pass directly from bank to bank perpendicularly; but if there is a current, its track will form a diagonal, and it will strike the opposite bank lower down, according to the rapidity of the stream and the slowness of the boat.

Another instance is afforded when a ferry-boat is anchored, by means of a long rope, to a point some distance above (*Fig.* 10); the boat being turned

Fig. 10.



obliquely, will pass from one bank to the other by the force of the current. Here the water tends to carry the boat downward, while the force of the rope acts upward; the boat passes between the two from bank to bank. The ascent of a kite is precisely similar, the wind and the string being counteracting forces. When a vessel sails under a side-wind, the resistance of the keel against the water, and the force of the wind against the sail, act in different directions, and produce a motion of the vessel between them.

CENTRIFUGAL FORCE.

All bodies, when in motion, have a tendency to move forward in a straight line. A stone thrown into the air is gradually bent from this straight course into a curve by the attraction of the earth. When a ball is shot from a gun, the force being greater, it flies in a longer and straighter curve. A familiar example also occurs, while driving a wagon rapidly, in attempting to turn suddenly to the right or left; the tendency of the load to move straight on will sometimes cause its overthrow. An observance of this principle would prevent the error which some commit by making sharp turns or angles in ditches and water-courses; the onward tendency of the water drives it against the bank, checks its course, and wears away the earth. By giving the ditch a curve, the water is but slightly impeded, and a much larger quantity will escape through a channel of any given size.

When a grindstone is turned rapidly, the water upon its surface is thrown off by this tendency to move in straight lines. In the same way, a weight fastened to a cord, whirled by the hand, will keep the cord stretched during the revolution. The same principle causes a stone, when it leaves a sling, to fly off in a line. This tendency to fly off from a revolving centre is called *centrifugal force*—the word *centrifugal* meaning *flying from the centre*. Large grindstones, driven with great velocity by machinery, are sometimes split asunder by centrifugal force.

The most sublime examples of centrifugal force occur in the motion of the earth and planets, which will be more fully explained on a future page.

CHAPTER III.

ATTRACTION.

SECTION I.

GRAVITATION.

THE earth, as is well known, is a mass of matter in the form of a globe, the diameter being upward of 7900 miles. From its enormous size and the small portion seen from one point, the surface appears flat, except where broken into mountains and valleys.

The tendency which all bodies possess of falling toward the earth is owing to the attractive force which this great mass of matter exerts upon them. This kind of attraction is called *gravitation*. The force with which a body is thus drawn is the *weight* of that body.

When a stone is dropped from the hand, its velocity is at first slow, but continues to increase till it strikes the earth; hence, the further it falls, the harder it will strike. This accelerated motion is precisely similar to that of a steam-boat when it first leaves the wharf; the force of gravity may be compared to the driving power of the engine, and the quickened velocity of the falling stone to the increased headway of the boat.

All bodies, whether large or small, fall equally fast, unless they are so light as to be borne up in part by the resistance of the air. In the first second of time they fall 16 feet; in the next second, 3 times 16, or 48 feet; in the third second, 5 times 16, or 80 feet, and so on. Or, if the whole distance fallen be taken togeth-

er, they fall 16 feet in one second, 4 times 16 in two seconds, 9 times 16 in three seconds, and so forth. In other words, the whole distance is equal to the square of the time. This is plainly exhibited by the following table:*

Seconds, from beginning to fall.	1	2	3	4	5	6
Whole height fallen in feet.	16	4×16 or 64.	9×16 or 144.	16×16 or 256.	25×16 or 400.	36×16 or 576.
Space fallen in each second in feet.	16	3×16 or 48.	5×16 or 80.	7×16 or 112.	9×16 or 144.	11×16 or 176.

A stone or other body will fall 1 foot in a fourth of a second, 3 feet the next fourth, 5 feet the third fourth, and 7 feet the last fourth; which is the same as 4 feet in half a second, 9 feet in three fourths of a second, and 16 feet for the whole second.

The depth of an empty well, or the height of a precipice, may be nearly ascertained by observing the time required for the fall of a stone to the bottom. The time may be measured by a stop-watch, or, in its absence, a pendulum may be made by fastening a pebble to a cord, which will swing from the hand in regular vibrations of an exact second each if the cord be $39\frac{1}{8}$ inches long, or of half a second each if it be about $9\frac{3}{4}$ inches long.

The velocity increases simply as the time—that is, the speed in falling is twice as great in two seconds as in one; three times as great in three seconds; four times as great in four seconds, and so forth. A stone will fall four times as far in two as in one second, while

* The distance, accurately stated, is sixteen feet and one inch for the first second, and hence the numbers in the table fall a very little short of the distance actually fallen.

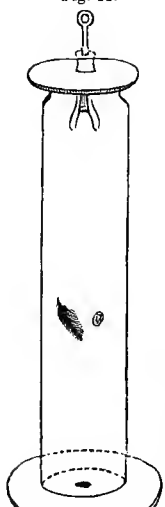
its velocity will be doubled; nine times as far in three seconds, while its velocity will be tripled, &c.

If a stone is thrown upward, its motion continues gradually to decrease, at the same rate as it increases in falling; hence the same time is required to reach its highest point, as to fall from that point back to the earth. Therefore the velocity with which it is first projected upward is equal to the velocity which it attains at the moment of striking the ground. There is an exception, however, to this general rule. In a vacuum it would be perfectly correct, but in ordinary practice the resistance of the air tends to diminish the velocity while as cending, and still further to retard it while descending. For this reason, it will fall with less speed than it first arose. For heavy bodies and small distances, this exception would be imperceptible; but with small bodies falling from great heights, the difference will be considerable.

The velocity of a stone after falling one second, or sixteen feet, is at the rate of thirty-two feet per second; hence, if thrown upward at that rate, it will rise just sixteen feet high. After falling three seconds, the rate is ninety-six feet; and hence, if projected upward at ninety-six feet per second, it will rise nine times sixteen feet, or one hundred and forty-four feet high. And so of other heights.

Were it not for the resistance of the air, a feather would fall as swiftly as a leaden ball. This is conclusively shown by an interesting experiment. A tall glass jar (*Fig.* 11), open at the bottom, is covered with a brass cap, fitting it air-tight. Through this cap passes an air-tight wire, which, by turning, opens a small pair

Fig. 11.



Feather and coin falling alike in a vacuum.

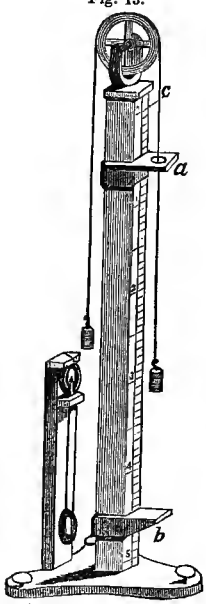
of pincers. Within these are placed a feather and a half dollar, and the air is then thoroughly drawn from the receiver by means of an air-pump. The wire is turned, and the feather and coin both drop at once, and strike the bottom at the same moment.

MEASURING THE VELOCITY.—ATWOOD'S MACHINE.

In consequence of the swiftness of falling bodies, it is not easy to measure the exact distance through which they fall in a given time. There is an instrument, however, known as *Atwood's Machine*, which renders their motion much slower, at the same time that the rate of increase in velocity is precisely the same, and it therefore admits of an exact measurement of the descent. The principle of this machine may be easily understood by *Fig.* 12, where two weights, hung on a fine silk cord running over a wheel, exactly balance each other. If now a small additional weight be placed on one of these, it will destroy the balance, and the weight will begin to move downward. As this little weight has to impart momentum to both the other larger weights, they will move as much slower than ordinary falling as the smaller weight is less than they. On this principle Atwood's Machine, represented by *Fig.* 13, is made.

Fig. 12.

Fig. 13.



Atwood's Machine for measuring the descent of bodies.

The two weights are first made to balance each other, when one of them is raised nearly to the wheel at *c*, and a small weight in the form of a short rod is placed across it. It immediately descends with *accelerated* or increasing velocity until it reaches the hole in the shelf *a*, through which the weight passes, but the rod is caught and retained. The motion is now no longer accelerated, because the weights have become equal, and the descending one continues to fall *uniformly* at the same rate that it passed through the hole in the shelf, until it strikes the bottom. During this time its velocity may be accurately measured by means of the clock and pendulum attached to the instrument. By sliding the shelf up or down, the velocity, after falling through different spaces to reach the shelf, may be accurately determined. When the shelf is placed very near the top, so that but little velocity is acquired, the descending weight will move very slowly all the way down; but when placed lower, the weight continues downward more rapidly. It is necessary that the wheel turn with extreme ease, to effect which, friction-wheels, described hereafter, are usually employed.

There are many instances showing the accelerated motion and increased force of falling bodies. When a

large stone rolls down a mountain, it first moves slowly, but afterward bounds with rapidity, sweeping before it all smaller obstacles. Hail-stones, although small, acquire such velocity as to break windows; and but for the resistance of the air, they would be much more destructive. The blow of a sledge-hammer is more severe as it is lifted to a greater height. Newton was first led to the examination of the laws of gravity by observing, when sitting under an apple-tree, that the fruit struck his hand with greatest severity when it fell from the top of the tree.

It is not an unusual error to suppose that a large body will fall more rapidly than a small one. Some can scarcely believe that a fifty-six pound weight will not drop with a greater velocity than a small nail, not remembering that a proportionately greater force is required to overcome the inertia and set the larger body in motion. This error existed for many centuries, from the time of Aristotle until Galileo first questioned its correctness. The celebrated experiment which established the truth on this subject, and led to the discovery of the laws of falling bodies just explained, and which formed an era in modern philosophy, was performed from the top of the leaning tower of Pisa. Galileo was a philosophical teacher, and, being a man who thought for himself, soon discovered, by reasoning, the errors that had been received without a doubt for more than twenty centuries. All the learning of the age and the wisdom of the universities were against him, and in favor of this time-honored error, the truth of which no one had ever thought of submitting to experiment. The hour of trial arrived, when he, an ob-

scure young man, stood nearly alone on one side, while the multitude, with all the power and confessed knowledge of the age, were on the other.

The balls to be employed were carefully weighed and scrutinized to detect deception, and the parties were satisfied. The one ball was exactly twice the weight of the other. The followers of Aristotle maintained that when the balls were dropped from the top of the tower, the heavy one would reach the ground in exactly half the time employed by the lighter ball. Galileo asserted that the weights of the balls would not affect their velocities, and that the times of descent would be equal. The balls were conveyed to the summit of the lofty tower—the crowd assembled round the base—the signal was given—the balls were dropped at the same instant, and swiftly descending, at the same moment struck the earth. Again and again the experiment was repeated with uniform results. Galileo's triumph was complete—not a shadow of doubt remained; but, instead of receiving the congratulations of honest conviction, private interest, the loss of place, and the mortification of confessing false teaching, proved too strong for the candor of his adversaries. They clung to their former opinions with the tenacity of despair, and he was driven from Pisa.*

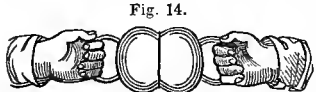
* Mitchell's Lectures.

SECTION II.

COHESION.

The attraction of gravitation, as we have just seen, takes place between bodies at a greater or less distance from each other. There is another kind of attraction, acting only when the parts of substances are in *actual contact;* this is called *cohesion.* It is this which holds the parts of a body together and prevents it from falling to pieces. It may be shown by taking two pieces of lead, and, after having made upon them two smoothly-shaven surfaces with a knife, pressing them firmly together with a twisting motion (*Fig.* 14). The asperities of the surfaces are thus pushed down, and the particles are brought into close contact, so that cohesion immediately takes place between them, and some force will be required to draw them asunder.* Two pieces of melted wax adhere together in the same way. Melted pitch or other similar substance, smeared thinly over the polished surfaces of metal or glass, also causes cohesion to take place between them. Smooth iron plates, two inches in diameter, have been made to stick together so firmly with hot grease as to require, when cold, a weight of half a ton to draw them apart. Plates of brass of the same size, cemented by means

Fig. 14.



Cohesive attraction in two lead balls.

* That this is not atmospheric pressure, like that which holds two panes of wet glass together, is shown by the fact that it requires nearly as great a force to separate them when they are placed under the exhausted receiver of an air-pump. Besides this, atmospheric pressure is much weaker than this force, with so small a surface.

of pitch, required 1400 pounds. On this principle depends the efficacy of those substances which are used for cementing broken vessels.

The most perfect artificial polish which can be given to hard metals is still so rough as to prevent the faces from coming into close contact; hence they must be either melted, or softened like iron when it is welded.

The different degrees of cohesion which take place between the particles of various soils, to reunite them after they have been crumbled asunder, occasion the main difference between light and heavy soils. When a light soil becomes soaked with water, the particles adhere in a very slight degree; and hence, when it becomes dry again, it is easily worked mellow. But if it be of a clayey nature, too much moisture softens it like melted wax: the particles are thus brought into close contact, and strong adhesion takes place; hence the hardness and difficulty of working such soils when again dried. This adhesion is lessened by applying sand, chip-dirt, straw, yard-manure, or by burning the earth, but more especially by thorough draining, which, preventing the clay from becoming so moist and soft, lessens the adhesion of its parts.

Different substances are hard, soft, brittle, or elastic, according to the different degrees or modes of action in the attraction of cohesion.

STRENGTH OF MATERIALS.

It is a matter of great utility in the arts to determine the different degrees of cohesion possessed by the different substances; or, in other words, to ascertain their *strength*. This is done by forming them into

rods of equal size, and applying weights to their lower extremities sufficient to break them, by drawing them asunder. The amount of weight shows their relative degrees of strength. The following table gives the weights required to break the different substances, *each being formed into a rod one quarter of an inch square:*

Woods.

Ash, toughest	1000 lbs.
Beech	718 "
Box	1250 "
Cedar	712 "
Chestnut	656 "
Elm	837 "
Locust	1280 "
Maple	656 "
Oak, white	718 "
Pine, white	550 "
" pitch	750 "
Poplar	437 "
Walnut	487 "

Metals.

Steel, best	9370 lbs.
" soft	7500 "
Iron, wire	6440 "
" best bar	4690 "
" common bar	3750 "
" inferior bar	1880 "
" east	1150 to 3100 "
Copper, wire	3800 "
" east	2030 "
Brass	2800 "
Platina wire	3300 "
Silver, cast	2500 "
Gold, cast	1250 "
Tin	310 "
Zinc, cast	160 "
" sheet	1000 "
Lead, east	55 "
" milled	207 "

From these tables we may ascertain the strength of chains, rods, &c., when made of different metals, and of timbers, bars, levers, swing-trees, and farm implements, when made of woods. Wood which will bear a very heavy weight for a minute or two will break with two thirds of the weight when left upon it for a long time. This explains the reason that store-house and barn timbers sometimes give way under heavy loads of grain, which have appeared at first to stand with firmness.

Although the preceding table gives the strength of wood drawn *lengthwise*, yet the comparative results are not greatly different when the force is applied in a *transverse* or *side* direction, so as to break in the usual way.

The following table shows the results of several experiments with pieces of wood one foot in length, one inch square, with the weight suspended from one end, bending them sidewise.

White oak, seasoned, broke with			240 lbs.
Chestnut,	"	"	170 "
White pine,	"	"	135 "
Yellow pine,	"	"	150 "
Ash,	"	"	175 "
Hickory,	"	"	270 "

A rod of good iron is about ten times as strong as the best hemp rope of the same size. The best iron wire is nearly twenty times as strong as a hemp cord. Hence the enormous strength of the wire cables, several inches in diameter, which are employed for the support of suspension bridges.

A rope one inch in diameter will bear about 5000 lbs., but in practice should not be subjected to more

than half this strain, or about one ton. The strength increases or diminishes according to the size of the cross-section of the rope; thus a cord half an inch in diameter will support one quarter as much as an inch, and a quarter-inch cord a sixteenth as much. A knowledge of the strength of ropes, as used by farmers in windlasses, pulleys, drawing loads, &c., would sometimes prevent serious accidents by their breaking. The following table may therefore be useful:

Diameter of rope or cord in inches.	Pounds borne with safety.	Breaking weight.
One eighth	31 lbs.	78 lbs.
One fourth	125 "	314 "
One half	500 "	1250 "
One	2000 "	5000 "
One and a quarter	3000 "	7500 "
One and a half	4500 "	12,500 "

These results will vary about one fourth with the quality of common hemp. Manilla is about one half as strong as the best hemp. The latter stretches one fifth to one seventh before breaking.

Wood is about seven to twenty times stronger when taken lengthwise with the fibres than when a side force is exerted, so as to *split* it. The splitting of timber or wood for fuel is, however, accomplished with a comparatively small power by the use of wedges, the force of heavy blows, and the leverage of the two parts.

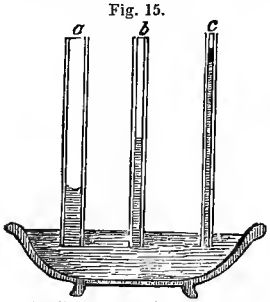
The attraction of cohesion is very weak in liquids; it is sufficient, however, to give a round or spherical shape to very small portions or single drops, and to furnish a beautiful illustration, on a minute scale, of the same principle which gives a rounded form to the surface of the sea. In one case, cohesion, by drawing toward a common centre, forms the minute globule of

dew upon the blade of grass; in the other, gravitation, acting in like manner, but at vast distances, gives the mighty rotundity to the rolling waters of the ocean.

CAPILLARY ATTRACTION.

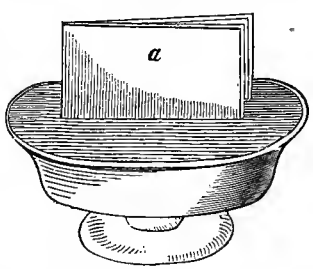
Capillary attraction is a species of cohesion; it takes place only between solids and liquids. It is this which holds the moisture on the surface of a wet body, and which prevents the water from running instantly out of a wet cloth or sponge. By touching the lower extremity of a lump of sugar to the surface of water in a vessel, capillary attraction will cause the water to rise among its granules and moisten the whole lump. It may be very distinctly shown by placing the end of a fine glass tube into water; the water will rise in it above the level of the surrounding surface. If the bore of the tube be the twelfth of an inch in diameter (*a*, *Fig.* 15), it will rise a quarter of an inch; if but the

Fig. 15.



Capillary attraction in tubes.

Fig. 16.



Capillary attraction between two panes of glass.

twenty-fifth of an inch in bore, as *b*, it will rise half an inch; but if only a fiftieth of an inch, the water will rise an inch. This ascent of the liquid is caused by the attraction of the inner surface of the tube, until the

weight of the column becomes equal to the force of the attraction. Capillary attraction may be also exhibited by two small plates of glass, placed with their edges in water, in contact on one side, and a little open at the other side, as in *Fig.* 16, p. 47. As the faces of the plates approach each other, the water rises higher, forming the curve, *a*.

Capillary attraction performs many important offices in nature. The moisture of the soil depends greatly upon its action. If the soil is composed of coarse sand or gravel, the interstices are large, and, like the larger glass tube, will not retain the rain which falls upon it. Such soils are, therefore, easily worked in wet weather, but become too dry in seasons of drought; but when the texture is finer, and especially if a due proportion of clay be mixed with the sand, the interstices become exceedingly small, and retain a full sufficiency of moisture. If, however, there is too much clay, the soil is apt to become close and compact, and the water can not enter until it is broken up or pulverized. It is for this reason that sub-soil plowing becomes so eminently beneficial, by deepening the mellow portion, and thus affording a larger reservoir, which acts like a sponge in holding the excess of falling rains, till wanted in the dry season. For the same reason, a well-cultivated soil is found to preserve its moisture much better during the heat of summer than a hardened and neglected surface.

If capillary attraction should cease to exist, the earth would soon become a barren and uninhabitable waste. The moisture of rains could not be retained by the particles of the soil, but would immediately

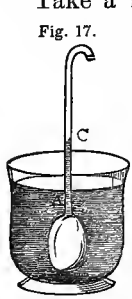
sink far down into the earth, leaving the surface at all times as dry and unproductive as a desert; vegetation would cease; brooks and rivers would lose the gradual supplies which the earth affords them through this influence, and become dried up; and all plants and all animals die for want of drink and nourishment. Thus the very existence of the whole human race evidently depends on a law, apparently insignificant to the unthinking, but pointing the observing mind to a striking proof of the creative design which planned all the works of nature, and fitted them with the utmost exactness for the life and comfort of man.

ASCENT OF SAP.

The following interesting experiments serve to explain the cause of the ascent of sap in plants and trees:

Take a small bladder, or bag made of any similar substance, and fasten it tightly on a tube open at both ends (*Fig.* 17); then fill them with alcohol up to the point C, and immerse the bladder into a vessel of water. The alcohol will immediately rise slowly in the tube, and if not more than two or three feet high, will run over the top. This is owing to the capillary attraction in the minute pores of the bladder, drawing the water within it faster than the same attraction draws the alcohol outward. One liquid will thus intrude itself into another with great force. A bladder filled with alcohol, with its neck tightly tied, will soon burst if plunged under water. If a bladder is filled with gum-water, and then immersed as before,

Fig. 17.



Apparatus explaining the rising of sap.

the water will find its way within against a very heavy pressure.

In this manner sap ascends through the minute tubes in the body of trees. The sap is thickened like gum-water when it reaches the leaves, and a fresh supply, therefore, enters through the pores in the spongelets of the roots by capillary attraction, and, rising through the stem, keeps up a constant supply for the wants of the growing tree.

SECTION III.

CENTRE OF GRAVITY.

THE *centre of gravity* is that point in every hard substance or body, on every side of which the different parts exactly balance each other. If the body be a globe or round ball, the centre of gravity will be exactly at the centre of the globe; if it be a rod of equal size, it will be at the middle of the rod. If a stone or any other substance rest on a point directly under the centre of gravity, it will remain balanced on this point; but if the point be not under the centre of gravity, the stone will fall toward the heaviest side.

Some curious experiments are performed by an ingenious management of the centre of gravity. A light cylinder of cork or pasteboard contains a concealed piece of lead, *g* (*Figure* 18). The lead, being heavier than the rest, will cause the cylinder to roll up an inclined plane, when placed as shown by the

Fig. 18.

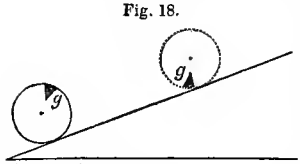
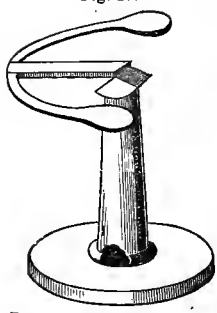


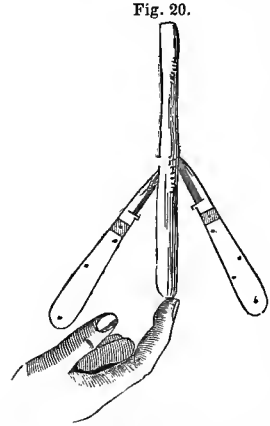
Fig. 19.



Body singularly balanced by lead knobs.

lower figure on the preceding engraving, until it makes half a revolution and reaches the place of the upper figure, when it will remain stationary. If a curved body, as shown in *Fig.* 19, be loaded heavily at its ends, it will rest on the stand, and present a singular appearance by not falling, the centre of gravity lying between the two heavy portions on the end of the stand. A light stick of some length may be made to stand on the end of the finger, by sticking in two penknives, so as to bring the centre of gravity as low as the finger-end (*Fig.* 20).

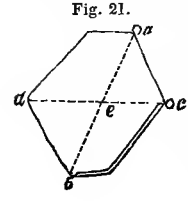
Fig. 20.



Centre of gravity maintained by two penknives.

If any body, of whatever shape, be suspended by a hook or loop at its top, it will necessarily hang so that the centre of gravity shall be directly under the hook. In this way the centre in any substance, no matter how irregular its shape may be, is ascertained. Suppose, for instance, we have the irregular plate or board shown in the annexed figure (*Fig.* 21): first hang it by the hook *a*, and the centre of gravity will be somewhere in the dotted line *a b*.

Fig. 21.



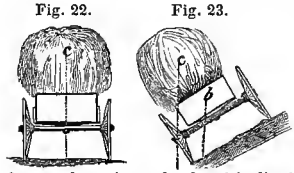
Then hang it by the hook *c*, and it will be somewhere in the line *c d*. Now the point *e*, where they cross each other, is the only point in both, consequently this is the centre sought. If the mass or body, instead of being flat like a board, be shapeless like a stone or lump of chalk, holes bored from different suspending points directly downward will all cross each other exactly at the centre of gravity.

LINE OF DIRECTION.

An imaginary line from the centre of gravity perpendicularly downward to where the body rests is called the *line of direction.*

Now in any solid body whatever, whether it be a wall, a stack of grain, or a loaded wagon, the line of direction must fall within the base or part resting upon the ground, or it will immediately be thrown over by its own weight. A heavily and evenly loaded wagon on a level road will be perfectly safe, because the line of direction falls equally between the wheels, as shown in *Fig.* 22, by the dotted line, *c* being the centre. But if it pass a steep side-hill road, throwing this line outside the wheels, as in *Fig.* 23, it must be instantly overturned. If, however, instead of the high load represented in the figure, it be some very heavy material, as brick or sand, so as not to be higher than the square box, the centre will be much lower down, or at *b*, and thus, the line falling within the wheels, the load will be safe from danger,

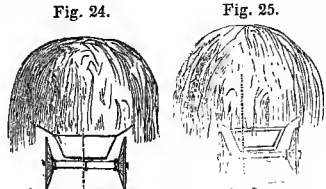
Fig. 22. Fig. 23.



Centre of gravity on level and inclined roads.

unless the upper wheel pass over a stone, or the lower wheel sink into a rut. The centre of gravity of a large load may be nearly ascertained by measuring with a rod; and it may sometimes happen that by measuring the sideling slope of a road, all of which may be done in a few minutes, a teamster may save himself from a comfortless upsetting, and perhaps heavy loss. Again, a load may be temporarily placed so much toward one side, while passing a sideling road, as to throw the line of direction considerably more up hill than usual, and save the load, which may be adjusted again as soon as the dangerous point is passed. This principle also shows the reason why it is safer to place only light bundles of merchandise on the top of a stage-coach, while all heavier articles are to be down near the wheels; and why a sleigh will be less likely to upset in a snow-drift, if all the passengers will sit or lie on the bottom. When it becomes necessary to build very large loads of hay, straw, wool, or other light substances, the "reach," or the long connecting-bar of the wagon, must be made longer, so as to increase the length of the load; for, by doubling the length, two tons may be piled upon the wagon with as much security from oversetting as one ton only on a short wagon.

Fig. 24. Fig. 25.



Centre of gravity of an even and one-sided load.

Where, however, a high load can not be avoided, great care must be taken to have it evenly placed. If, for instance, the load of hay represented by *Figure* 24 be skillfully built, the line of direc-

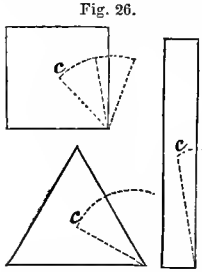
tion will fall equally distant within each wheel; but a slight misplacement, as in *Fig.* 25, p. 53, will so alter this line as to render it dangerous to drive except on a very even road.

Thus every one who drives a wagon should understand the laws of nature sufficiently to know how to arrange the load he carries. It is true that experience and good judgment alone will be sufficient in many cases; but no person can fail to judge better, with the reasons clearly, accurately, distinctly before his eyes, than by loose conjecture and random guessing.

Every farmer who erects a wall or building, every teamster who drives a heavy load, or even he who only carries a heavy weight upon his shoulder, may learn something useful by understanding the laws of gravity.

It is familiar to every one, that a body resting upon a broad base is more difficult to overset than when the base is narrow. For instance, the square block (*Fig.* 26) is less easily thrown over than the tall and narrow block of equal weight, because, in turning the square block over its lower edge, the centre of gravity must be lifted up considerably in the curve shown by the dotted line *c;* but with a tall, narrow block, this curve being almost on a level, very little lifting is required. Hence the reason that a high load on a wagon is so much more easily overturned than a low one.

Fig. 26.

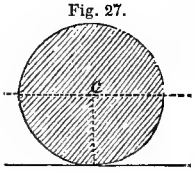


Of all forms, a pyramid stands the most firmly on its

base. The centre of gravity, *c* (*Fig.* 26), being so near the broad bottom, it must be elevated in a very steep curve to throw the line of direction beyond the base. For this reason, a stone wall, or the dam for a stream, will stand better when broad at bottom and tapering to a narrow top than if of equal thickness throughout.

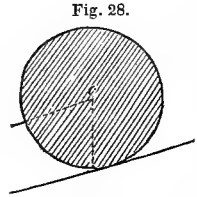
When a globe or round ball is placed upon a smooth floor, it rests on a single point. If the floor be *level*, the line of direction will fall exactly at this resting-point (*Fig.* 27). To move the ball, the centre will move precisely on a level, without being raised at all. This is the reason that a ball, a cylinder, or a wheel is rolled forward so much more easily than any flat-sided or irregular body. In all these cases, the line of direction, although constantly changing its place, still continues to fall on the very point on which the round body rests.

Fig. 27.



But if the level floor is exchanged for a slope or inclined plane (*Fig.* 28), the line of direction no longer falls at the touching-point, but on the side from it downward; the ball will therefore, by its mere weight, commence rolling, and continue to do so till it reaches the bottom of the slope.

Fig. 28.



Wheel-carriages owe their comparative ease of draught to the fact that the centre of gravity in the load is moved forward by the rolling of the wheels, on a level, or parallel with the surface of the road, just in the same way that the round ball rolls so easily. Each

wheel supporting its part of the load at the hub, the same rule applies to each as to a ball or cylinder alone. Hence, on a level road, the line of direction falls precisely where the wheels rest on the ground, but if the road ascend or descend, it falls elsewhere; this explains the reason why it will run by its own weight down a slope.

Whenever a stone or other obstruction occurs in a road, it becomes requisite to raise the centre by the force of the team and by means of oblique motion, so as to throw the wheel over it, as shown by *Fig.* 29. One of the reasons thus becomes very plain why a large wheel will run with more ease on a rough road than a smaller one; the larger one mounting any stone or obstruction without lifting the load so much out of a level or direct line, as shown by the dotted lines in the annexed figures (*Figs.* 29 and 30). Another reason is, the large wheel does not sink into the smaller cavities in the road.

Fig. 29.

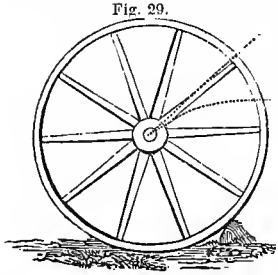


Fig. 30.

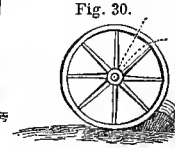
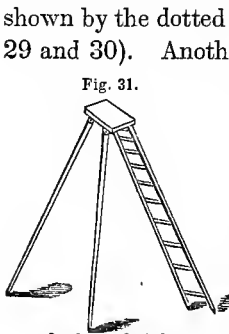


Fig. 31.



A firmly-set fruit-ladder.

Fig. 32.

A dangerously-set fruit-ladder.

A self-supporting fruit-ladder (*Figure* 31) (the centre of gravity, when in use, being at or near the top) must have its legs more widely spread, to be secure from fall-

ing, than if the centre were lower down. Hence such a position as in *Fig.* 32 would be unsafe.

The support of the human body, in standing and walking, exhibits some interesting examples in relation to this subject. A child can not learn to walk till he acquires skill enough to keep his feet always in the line of direction. When he fails to do this, he topples over toward the side that the line falls outside his feet. A man standing with his heels touching the washboard of a room can not possibly stoop over without falling, because, when he bends, the line of direction falls forward of his toes, the wall against which he stands preventing the movement of his body backward to preserve the balance.

In walking, the centre rises and falls slightly at each step, as shown by the waved line in *Fig.* 33. If it were not for the bending of the knee-joints, this exercise would be much more laborious, as it would then become needful to throw the centre into an upward curve at every step. For this reason, a wooden leg is more imperfect than the natural one (*Fig.* 34). Hence the reason why walking on crutches is laborious and fatiguing, because at every onward step the body must be thrown upward in a curve, like a wagon mounting repeated obstructions.

Fig. 33.

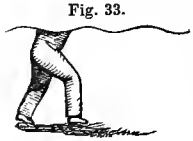


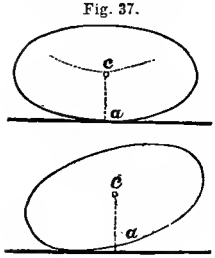
Fig. 34.

When a load is carried on the shoulder, it should be so placed that the line of direction may pass directly through the shoulder or back down to the feet, *Fig.* 35, p. 58. An unskillful person will sometimes place

Fig. 35. Fig. 36.

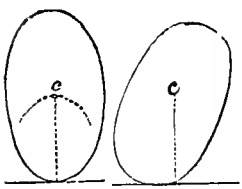
a bag of grain as shown in *Fig.* 36. The line falling outside his feet, he is compelled to draw downward with great force on the other end of the bag. A man who carries a heavy pole on his shoulder should see that the centre is directly over his shoulder, otherwise he will be compelled to bear down upon the lighter end, and thus add in an equal degree to the weight upon his body.

Fig. 37.



If an elliptical or oval body, *Fig.* 37, rest upon its side *a*, rolling it in either direction elevates the centre, *c*, because it is nearest the side on which the body rests. If, when raised, it be suffered to fall, its momentum carries it beyond the point of rest, and thus it continues rocking until the force is spent. The course of the centre during these motions is shown by the curved dotted line, *c*. If it be placed upon end, as in *Fig.* 38, then any motion toward either side brings the centre of gravity nearer the touching-point, that is, causes it to descend, and the body consequently falls over on its side. This may be easily illustrated with an egg, which will lie at rest upon its side, but falls when set on either end.

Fig. 38.



The rockers of chairs, cradles, and cribs are formed on the principle just explained. If so made that the

centre of gravity of the chair or cradle is nearer the middle of the rocker than to the ends, the rocking motion will take place; and when the distance from the centre of gravity to the ends of the rockers is but little greater than the distance to the middle, *c*, as in *Fig.* 39, the motion will be slow and gentle; but if this difference be greater, as in *Fig.* 40, it will be rapid. When the centre is high, the rockers must have less curvature than where it is low and near the floor. If the centre of gravity be nearer the ends than to the middle, the chair will immediately be overturned. This principle should be well understood in the construction of all instruments which move by rocking.

Fig. 39.

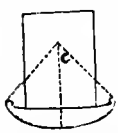
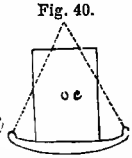


Fig. 40.



CHAPTER IV.

SIMPLE MACHINES, OR MECHANICAL POWERS.

SECTION I.

ADVANTAGES OF MACHINES.

THE moving forces which are applied to various useful purposes commonly require some change in velocity, direction, or mode of acting before they accomplish the desired end. For example, a running stream of water has a motion in one direction only; by the use of machinery, we change this to an alternating motion, as in the saw of the saw-mill, or to a rotatory or whirling motion, as in the stones of a grist-mill. The direct or straightforward power of a yoke of oxen is made, by the employment of the plow, to produce a side-motion to the sod as well as to turn it through half a circle. The thrashing-machine converts the slowly-acting pace of horses to the swift hum of the spiked cylinder.

Any instrument used for thus changing or modifying motion is called *a machine*, whether it be simple or complex in its structure. Thus even a *crowbar*, used in lifting stones from the earth, by diminishing the motion given by the hand and increasing its power, may be strictly termed a machine; while a *harrow*, which neither alters the course nor changes the velocity of the force applied, may with more propriety be regarded as simply an implement or tool. In common

language, however, these distinctions are not accurately observed, and a machine is usually considered to be any instrument consisting of different moving parts.

All machines, however complex, may be resolved into two simple parts, or simple machines. These are,

1. THE LEVER;
2. THE INCLINED PLANE.

The *wheel and axle*, and the *pulley*, are modified applications of the LEVER; and the *wedge* and the *screw* of the INCLINED PLANE, as will be shown on the following pages. These six are usually termed the *mechanical powers*. As they really do not possess any *power* in themselves, but only regulate power, the term "simple machines" may be regarded as most correct.

THE LAW OF VIRTUAL VELOCITIES.

Before proceeding to the simple machines, it may be well to explain a very important truth, which should be considered as lying at the foundation of all mechanical philosophy, and which renders plain and simple many things which would otherwise seem strange or contradictory. This is, that the force required to lift any given body is always in proportion to the weight of that body, taken together with the height to be raised. For instance, it requires twice the force to raise two pounds as to raise one pound, three times the force to raise three pounds, and so forth. Also, twice as great a force is needed to elevate any weight two feet as one foot, or three times as great for three feet, and so on. Again, combining these together, four times as great a force is required to raise two pounds to a height of two feet as to raise one pound only one foot; eight times

as great for four feet, and so on. This holds true, no matter by what kind of machinery it is accomplished. Now this may all seem very simple, but it serves to explain many difficult questions in relation to the real power possessed by all machines.

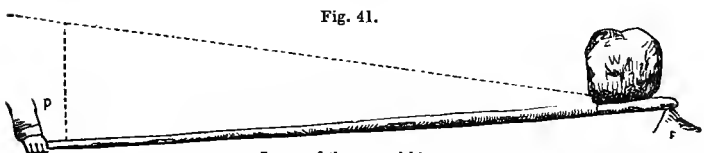
Take another example. Suppose that one wishes to raise a weight of 1000 pounds to a height of one foot. If his strength is only equal to 100 pounds, the weight would be ten times too heavy for him. He might, therefore, divide it into ten equal parts of 100 pounds each. Raising each part separately the required height of one foot, would be the same as raising one of them ten feet high. The weight is lessened ten times, but the distance is increased ten times. But there are some bodies, as, for example, blocks of stone or sticks of timber, which can not well be divided into parts in actual practice. He therefore resorts to a machine or mechanical power, through which the same result is accomplished by raising the whole weight in one mass with his single strength; but in this case as well as the other, the moving force which he applies must pass through ten times the space of the weight. We arrive, therefore, at the general rule, that the distance moved by the weight is as much less than that moved by the power as the power is less than the weight. This rule is termed by some writers the "*rule of virtual velocities*," *virtual* meaning not apparent or actual, but according to the real effect, because the increase in the velocity of the power makes up for increase in the size of weight. This rule will be better understood after considering its application to the different simple machines.

SECTION II.

THE LEVER.

THE simplest of all machines is the *lever*. It consists of a rod or bar, one end resting upon a prop or *fulcrum*, F (*Fig.* 41), near which is the weight, W, moved

Fig. 41.



Lever of the second kind.

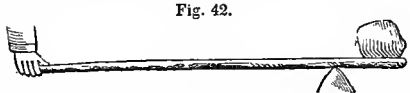
by the hand at P. The stone may weigh 1000 pounds; yet, if it is ten times as near the fulcrum as the man's hand is, a force of 100 pounds will lift it; but it will be moved only a tenth part as high as the hand has been moved, as shown by the dotted lines. By placing the stone still nearer the fulcrum, still less will be the power required to raise it, but then the distance elevated would be also still less. By sufficiently increasing the disproportion between the two parts of the lever, the strength of a child merely might be made to move more than many horses could draw.

These performances of the lever often excite astonishment at what appears to be out of the common course of things; yet, when examined by the principles of mechanics, instead of appearing matters of astonishment, they are found to be only the natural and necessary results of the laws of force. In the case of the lever just described, it is often incorrectly supposed that the power itself sustains the weight. But this is

not the case; nearly the whole of it rests upon the fulcrum. We often see proofs of this error in common practice, where fulcrums or props entirely insufficient to uphold the enormous weight to be raised are attempted to be used. If the weight, for instance, be ten times as near the fulcrum as to the power, then nine tenths of the weight rests upon the fulcrum, and the remaining tenth only is sustained by the lifting power. The lever only allows the power to expend itself through a longer distance, and thus, by concentrating itself at the weight, to elevate the latter through the shorter distance, according to the rule of virtual velocities already explained.

The fulcrum may be placed between the weight and the power, as in *Fig.* 42, or the power may be placed between the fulcrum and the weight, as in *Fig.* 43, the same principle of virtual velocities applying in all cases.

Fig. 42.



Lever of the first kind.

Fig. 43.

Lever of the third kind.

Where the fulcrum is between the power and the weight, as in *Fig.* 42, it is called a *lever of the first kind.*

Where the weight is between the fulcrum and the power, as in *Fig.* 41, it constitutes a *lever of the second kind.*

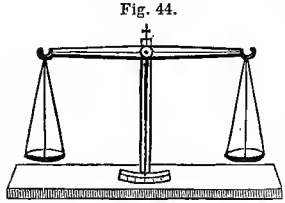
Where the power is between the fulcrum and the weight, as in *Fig.* 43, it is termed a *lever of the third kind.*

1. Many examples occur in practice of levers of the first kind. A crowbar, used to raise stones from the earth, is an instance of this sort; so is a handspike of any kind used in the same way. A hammer for drawing a nail operates as a lever of the first kind, the heel being the fulcrum, the nail the weight, and the hand the power; the distance through which the handle passes being several times greater than that of the claws, the force exerted on the nail is increased in like proportion. A pair of scissors consists of two levers, the rivet being the fulcrum; and in using them, as every one has observed, a greater cutting force is exerted near the rivets than toward the points. This is owing to the power being expended through a greater distance near the points, according to the rule already explained. Pincers, nippers, and other similar instruments are also double levers of the first kind.

A common steelyard is another example, the sliding weight becoming gradually more effective as it is moved further from the fulcrum or hook supporting the instrument. The brake or handle of a pump is a lever of this class, the pump-rod and piston being the weight.

The common balance is still another, the two arms being exactly equal, so that one weight will always balance the other, and on this its usefulness and accuracy entirely depends. The most sensitive balances have light beams with long arms, and the turning-point of hardened steel or agate, in the form of a thin wedge, on which the balance turns al-

Fig. 44.

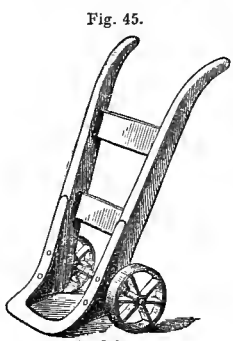


most without friction. Small balances have been so skillfully constructed as to turn with one thousandth part of a grain.

2. Levers of the second kind are less numerous, but not uncommon. A handspike used for rolling a log is an example. A wheel-barrow is a lever of the second kind, the fulcrum being the point where the wheel rests on the ground, and the weight the centre of gravity of the load. Hence, less exertion of strength is required in the arm when the load is placed near the wheel, except where the ground is soft or muddy, when it is found advantageous to place the load so that the arm shall sustain a considerable portion, to prevent the wheel sinking into the soil. A two-wheeled cart is a similar example; and, for the same reason, when the ground is soft, the load should be placed forward toward the horse or oxen; on the other hand, on a smooth and hard, or on a plank road, the load should be more nearly balanced. An observance of this rule would often save a great deal of needless waste of strength.

A sack-barrow, used in barns and mills for conveying heavy bags of grain from one part of the floor to another, is a lever nearly intermediate between the first and second kind, the weight usually resting very nearly over the fulcrum or wheels. When the bag of grain is thrown forward of the wheels, it becomes a lever of the first kind; when back of the wheels, it is a lever of the second kind. As it is

Fig. 45.



Sack-barrow.

used only on hard and smooth floors, and not, like the wheel-barrow, on soft earth, the more nearly the load is placed directly over the wheels, the more easily they will run.

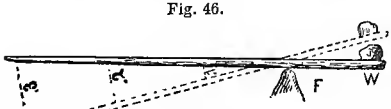
3. In a lever of the third kind, the weight being further from the fulcrum than the power, it is only used where great power is of secondary importance when compared with rapidity and dispatch. A hand-hoe is of this class, the left hand acting as the fulcrum, the right hand as the power, and the resistance overcome by the blade of the hoe as the weight. A hand-rake is similar, as well as a fork used for pitching hay. Tongs are double levers of this kind, as also the shears used in shearing sheep. The limbs of animals, generally, are levers of the third kind. The joint of the bone is the fulcrum; the strong muscle or tendon attached to the bone near the joint is the power; and the weight of the limb, with whatever resistance it overcomes, is the weight. A great advantage results from this contrivance, because a slight contraction of the muscle gives a swift motion to the limb, so important in walking and running, and in the use of the arms.

SECTION III.

ESTIMATING THE POWER OF LEVERS.

THE power of any lever is easily calculated by measuring the length of its two arms, that is, the two parts into which it is divided by the weight,

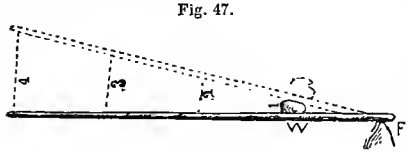
Fig. 46.



Lever of the first kind.

fulcrum, and power. In a lever of the first kind, if the weight and power be equally distant from the fulcrum, they will move through equal distances, and nothing will be gained; that is, a power of 100 pounds will lift a weight of 100 pounds only. If the power be twice as far as the weight, its force will be doubled; if three times, it will be tripled; and so forth. In a lever of the second kind, if the weight be equidistant between the fulcrum and power, the power will move through twice the distance of the weight, and the power of the instrument will therefore be doubled; if twice as far, it will be tripled, and so on, as shown in the annexed figures. The same mode of reasoning will explain precisely to what extent the force is diminished in levers of the third kind.

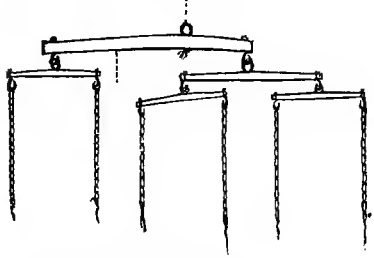
Fig. 47.



Lever of the second kind.

These rules will show in what manner a load borne on a pole is to be placed between two persons carrying it. If equidistant between them, each will sustain a like portion. If the load be twice as near to one as to the other, the shorter end will receive double the weight of the longer. For the same reason, when three horses are worked abreast, the two horses placed together should have only half the length of arm of the main whipple-tree as the single horse, *Fig.* 48. The farmer who has a team of two horses unlike in strength, may thus easily know how to adjust the arms of the whipple-tree so as to correspond with the strength of each. If, for instance, one of the horses possesses a strength

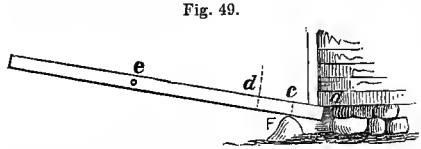
Fig. 48.



as much greater than the other as four is to three, then the weaker horse should be attached to the arm of the whipple-tree made as much longer than the other arm as four is to three.

In all the preceding estimates, the influence of the weight of the lever has not been taken into consideration. In a lever of the first kind, if the thickness of the two arms be so adjusted that it will remain balanced on the fulcrum, its weight will have no other effect than to increase the pressure on the fulcrum; but if it be of equal size throughout, its longer arm, being the heaviest, will add to its power. The amount thus added will be equal to the excess in the weight of this arm, applied so far along as the centre of gravity of this excess. If, for example, a piece of scantling twelve feet long, *a b*, *Fig.* 49, be used as a lever to lift the corner of a building, then the two portions, *a c*, *c d*, will mutually balance each other. If these be each a foot in length, the weight of ten feet will be left to bear down the lever. The cen-

Fig. 49.



tre of gravity of this portion will be at *e*, six feet from the fulcrum, and it will consequently exert a force under the building equal to six times its own weight. If the scantling weigh five pounds to the foot, or fifty pounds for the excess, this force will be equal to three hundred pounds.

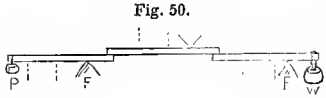
In the lever of the second kind, its weight operates *against* the moving power. If it be of equal size throughout, this will be equal to just one half the weight of the lever, the other half being supported by the fulcrum.

With the lever of the third kind, the rule applied to the first must be exactly reversed.

COMBINATION OF LEVERS.

A great power may be attained without the inconvenience of resorting to a very long lever, by means of a *combination of levers*. In *Fig.* 50, the small weight P, acting as a moving power, exerts a three-fold force on the next lever; this, in its turn, acts in the same degree on the third, which again increases the power three times. Consequently, the moving power, P, acts upon the weight, W, in a twenty-seven-fold degree, the former passing through a space twenty-seven times as great as the latter.

Fig. 50.

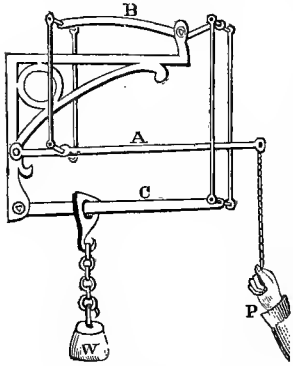


A combination of levers like this is employed in self-regulating stoves. It is in this case, however, used to multiply instead of to diminish motion. The expansion of a metallic rod by heat the hundredth part of an inch acts on a set of iron levers, and the motion is in-

creased, by the time it reaches the draught-valve, to about one hundred times.

A more compact arrangement of compound levers is shown in *Fig.* 51, where the power, P, acts on the lever A, exerting a force on the lever B five times as great as the power. B acts on the lever C with a force increased three times, and this, again, on the weight, W, with a four-fold force. Multiplying 5, 3, and 4 together, the product is 60; hence a force of one pound at P will support 60 pounds at W. By graduating (or marking into notches) the lever C, so that the distance is measured as the weight is moved along it, a compact and powerful steelyard for weighing is formed.

Fig. 51.

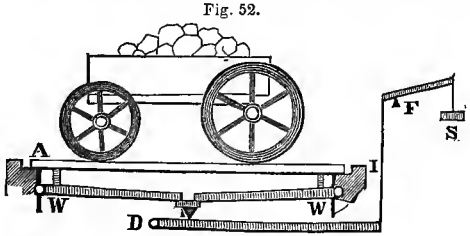


Compound levers.

WEIGHING MACHINE.

A valuable combination of levers is made in the construction of the *weighing machine*, used for weighing

Fig. 52.



Weighing Machine.

cattle, wagons loaded with hay, and other heavy articles. The wagon rests on the platform A (*Fig.* 52, p. 71), and this platform rests on two levers at W, W, which presses their other ends both on a central point, and this again bears on the lever D, the other end of which is connected by means of an upright rod with the steelyard at F.

There are two important points gained in this combination. In the first place, the levers multiply the power so much that a few pounds' weight will balance a heavy load of hay weighing a ton or more; and, in the next, the load resting on both the levers, communicates the same force of weight to the central point, from whatever part of the platform it happens to stand on; for if it presses hardest on one lever, it bears lighter, at a corresponding rate, on the other. In practice, there are always two pairs, or *four* levers, which proceed from each corner of the platform, and rest on one point at the centre. We have taken the two only, to simplify the explanation.

STUMP MACHINES.

A simple contrivance for allowing a succession of efforts in the use of the lever is represented in the accompanying figure (*Fig.* 53), and is used for tearing out the roots of partly decayed stumps. It may be also applied to lifting heavy weights, and to various other purposes. Two pieces of strong, three-inch white-oak plank, eight inches wide and seven feet long, are connected at the ends, and are furnished with the movable leg, *d*. Two rows of holes are bored through them, to receive iron pins, which are to serve as ful-

Fig. 53.

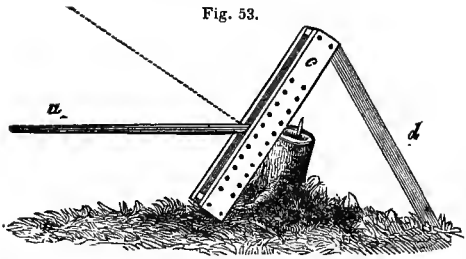
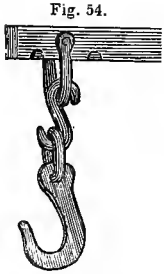


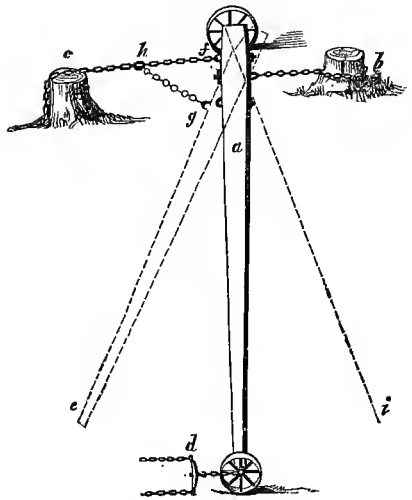
Fig. 54.



crums. A strong lever, *a*, is furnished at one end with a thick iron hook (shown in *Fig.* 54), which is first fastened on the root of the stump, and then one of the pins is inserted under the lever. The lever is now elevated, and the other bolt is placed under it. It is next pressed down, and the first bolt elevated one hole higher, and so on till the stump is torn out. To prevent the lever slipping, a notch is made in its under side, on each side of the hook, as shown in *Fig.* 54.

A more powerful stump-extracting machine, made on precisely the same principle, is exhibited by *Fig.* 55, p. 74. The lever, *a*, should be a strong stick of timber, furnished with three massive iron hooks, secured by bolts passing through, as represented in the figure. Small or truck wheels are placed at each end of the lever, merely for the purpose of moving it easily over the ground. The stump, *b*, used as a fulcrum, has the chain passing round near its base, while another chain passes over the top of the stump, *c*, to be torn out. A horse is attached to the lever at *d*, and, moving to *e*, draws the other end of the lever back-

Fig. 55.



ward, and loosens the stump; while in this position, another chain is made to connect *g* to *h*, and the horse is turned about, and draws the lever backward to *i*, which still further increases the loosening; a few repetitions of this alternating process tears out the stump. Very strong chains are requisite for this purpose. Large stumps may require an additional horse or a yoke of oxen. Where the stumps are remote from each other, iron rods with hooks may be used to connect the chains.

The power which may be given to this and to all other modes of using the lever, as we have already seen, depends on the difference between the lengths of its two arms. A yoke of oxen, drawing with a force of 500 pounds on the long arm of a lever 25 feet long, will exert a force on the short arm of six inches equal

to 50 times 500 pounds, or 25,000 pounds, on the stump.

It was after an examination of the great power which may be given to the lever by increasing this difference that Archimedes exultingly exclaimed, "Give me but a fulcrum whereon to place my lever, and I will move the earth!" Admitting the *theoretical* truth of this exclamation, and supposing there could be a lever which he might have used for this purpose, its practical impossibility may be quickly understood by computing the whole bulk of the globe; for such is its enormous size and cubical contents, that Archimedes must have moved forward his lever with the strength of a hundred pounds and the swiftness of a cannon ball for eight hundred million years to have moved the earth the thousandth part of an inch!

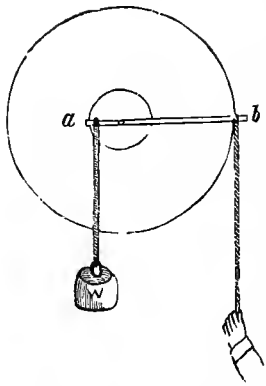
SECTION IV.

WHEEL AND AXLE.

In treating of the lever, it was shown to be capable of exerting a force through a small distance only. Hence, if a heavy body were required to be elevated to any considerable height, it would be necessary to accomplish it by a succession of efforts. This inconvenience is removed by a constant and unremitted action of the lever in the form of the *wheel* and *axle*.

Let the weight, *w* (*Fig.* 56, p. 76), be suspended by a cord from the end of the lever, *a b*, and a wheel attached to the lever, so that this cord may wind upon it as the weight is elevated; then let the power be applied at the other end by means of a cord, and a larger

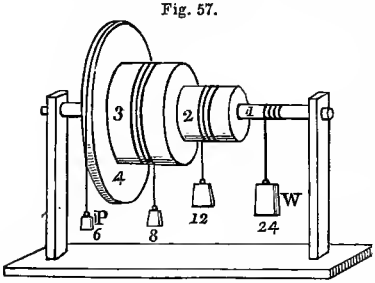
Fig. 56.



wheel be attached, so that this cord too may wind upon the larger wheel. These two wheels (fastened together so as to form one), as they are made to revolve on their axis, will now constitute, in a manner, a succession of levers, acting through an indefinite distance according to the length of the cords. The levers here successively acting are of the "first kind," and the axis of the wheel is the fulcrum. This arrangement constitutes in substance *the wheel* and *axle;* and its power, like that of the simple lever, depends on the comparative velocity of the weight and the moving force. If, for example, the larger wheel is four times the circumference of the smaller, a force of one hundred applied to the outer cord will raise a weight of four hundred pounds.

The annexed figure exhibits at one view the power exerted through the wheel and axle, where a small weight of 6 pounds will wind up (or balance) other weights separately, weighing 8, 12, or 24 pounds, as the difference increases between the size of

Fig. 57.



Wheel and axle, showing the heavier weight for less motion.

the wheel and of the axle, according to the rule of virtual velocities already explained.

The thickness of the rope has not been taken into consideration. This is very small when compared with the diameter of the outer wheel, but often considerable when compared with that of the inner. To be strictly accurate, therefore, the force must be considered as acting at the centre of the rope; hence the diameter of the rope must be added to the diameter of the wheel.

There are various forms of the wheel and axle. In the common windlass, motion is given to the axle by means of a winch, which is a lever like the handle of a grindstone. The windlass used in digging wells has usually four projecting levers or arms. The wheel used in steering a vessel is furnished with pins in the circumference, to which the hand is applied in turning it. In the capstan (for weighing anchor) the axis is vertical, and horizontal levers are applied around it, so that several men may work at once. The power of all these forms is easily calculated by the rule of virtual velocities—that is, that the velocity with which the power moves is as many times greater than the velocity of the weight, as the weight exceeds the power. A simple and convenient rule for computing in numbers the power of wheel-work is the following: Multiply all the numbers together which express either the circumferences or diameters of the large wheels, and then multiply together all the numbers which express the diameters of the smaller wheels or pinions; divide the greater number by the lesser, and the quotient will be the power sought.

MOLE PLOW.

A good example of the power of the wheel and axle is furnished in the English *Mole Plow* for draining land (*Fig.* 58). It has a wooden beam, sheathed with

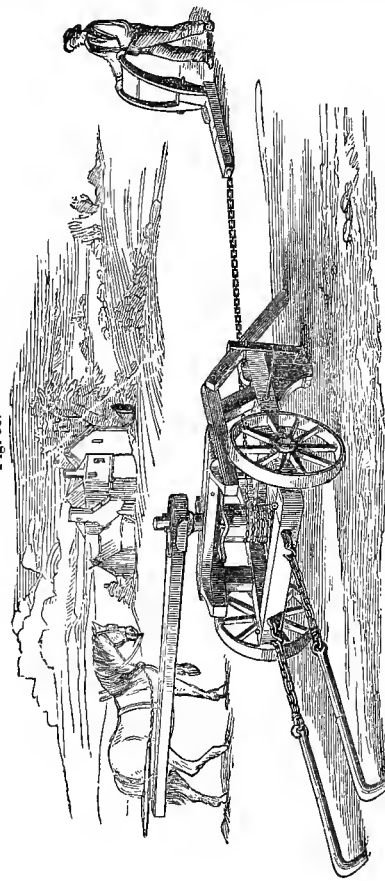


Fig. 58.

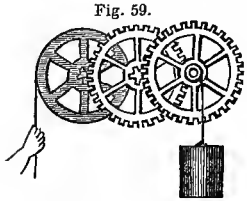
Mole Plow, drawn by a windlass with horse-power, forming a hole for drainage in clay soil.

iron on the lower side, which moves close to the ground, below which a thin, broad coulter extends downward, and to the lower end of this coulter a sharp iron cylinder is attached. This moves horizontally, point foremost, through the soil, producing a hollow channel beneath the plow for the escape of the water, the only trace on the surface being a narrow slit left by the coulter. It is dragged forward by means of a chain and capstan worked by a horse, the machine itself being fixed with strong iron anchors. This mode of draining is only adapted to clay soil, and is very cheaply performed, but is now little used since the introduction of tile-draining. *Fowler's Draining Plow*, described hereafter, is a great improvement on the mole plow, and draws the tile-tubing into the channel as fast as it is made, forming a perfect drain by one operation.

BAND AND COG WHEELS.

Where great power is required, several wheels and axles may be combined in a manner corresponding with that of the compound system of levers already explained. In this case the axis of one wheel acts on the circumference of the next, producing a continued slower motion, and increasing the power in a corresponding degree. The wheels are made thus to act by means of cogs or teeth, or of bands (*Fig.* 59). In ordinary practice, however, combined wheels are made use of to multiply motion instead of to diminish

Fig. 59.



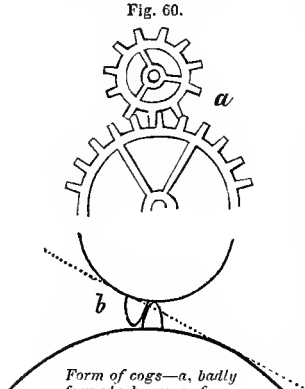
Combined cog-wheels.

it, familiar instances of which occur in the grist-mill and thrashing-machine.

In connecting a system of wheels, the cord or strap may be used where great force is not required, the friction round the circumference being sufficient to prevent slipping. Bands are chiefly useful where motion is to be transmitted to a distance; as, for example, from a horse-power without a barn to a thrashing-machine within it. Liability of sliding is sometimes useful, by preventing the machinery from breaking when a sudden obstruction occurs. Where the force is great, the necessary tension or tightness of the cord produces too great a friction at the axle. In such cases, cogs or teeth must be resorted to.

The term *teeth* is usually applied when they are formed of the same piece as the wheel, as in the case of cast-iron wheels. *Cogs* are teeth formed separately and inserted into the wheel, as with wooden wheels. *Pinions* are the small wheels, or, more properly, teeth set on axles.

Fig. 60.



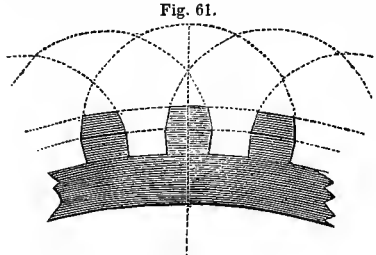
Form of cogs—a, badly formed; b, proper form.

FORM OF TEETH OR COGS.

The form of the teeth has a great influence on the amount of friction among wheel-work. Badly-formed teeth are represented by the wheel-work at *a*, in the annexed figure, consisting of square projecting pins. When these teeth first come into

contact with each other, they act *obliquely* together, and thus a part of their force is lost, and they continue scraping together with a large amount of friction so long as they remain in contact. These effects are avoided by giving to them the curved form represented by *b*. Here, instead of pressing each other obliquely, they act at right angles, that is, not obliquely; and instead of scraping, they *roll over* each other with ease. These curves are ascertained by mathematical calculation, which can not be here given; it may be enough to state that they should be so formed that the points in contact shall always work at right angles to each other. For ordinary practical purposes, however, they may be made as is shown in the annexed figure (*Fig.* 61), by striking circles whose diameter shall embrace just three teeth. The points of the teeth thus formed are removed, leaving a blunt extremity, according to the figure.

Fig. 61.



Mode of giving the best form to cogs.

There are a few other rules that should always be observed in constructing wheel-work, in order that the wheels may run easily together, without jerking or rattling, the most important of which are the following:

1. The teeth must be of uniform size and distance from each other, through the whole circumference of the wheel.

2. Any tooth must begin to act at the same instant

that the preceding tooth ceases to touch its corresponding tooth on the other wheel.

3. There must be sufficient space between the teeth not only to admit those of the other wheel, but to allow a certain degree of play, which should be equal to at least one tenth of the thickness of the teeth.

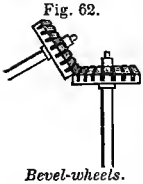
4. The pinions should not be very small, unless the wheels they act on are quite large. In a pinion that has only eight teeth, each tooth begins to act before it reaches the line of the centres, and it is not disengaged as soon as the next one begins to act. A pinion of ten teeth will not operate perfectly if working in a wheel of less than 72 teeth. Pinions of less than six teeth should never be used.

5. To give strength to the teeth of wheels, make the wheels themselves thicker, which increases the breadth of the teeth.

6. Wheel-work is often defective in consequence of the relative number of teeth working together not being such as to equalize the wear of all alike. If the number of teeth on a wheel is divided without a remainder by the number of the pinion, then the same teeth will repeatedly engage each other, and they will often wear unevenly. The number should be so arranged that every tooth of the pinion may work in succession into the teeth of the wheel. This is best effected by first taking a number for the wheel that will be evenly divided by the number on the pinion, and then adding *one more* tooth to the wheel. This will effect a continual change, so that no two shall be engaged with each other twice until all the rest have been gone through with. This odd tooth is called the *hunting-cog*.

Cog-wheels are most usually made with the teeth on the outside or circumference of the wheel; these are termed *spur-wheels*. If the teeth are set on *one side* of the wheels, they are termed *crown-wheels*. When they are made so as to work together obliquely, they are called *bevel-wheels*, as in *Fig.* 62.

Fig. 62.



Bevel-wheels.

Where the obliquity is small, the motion may be communicated by means of the *universal joint*, as shown in *Fig.* 63. This is commonly used in the thrashing-machine, where there is a slight change in the direction of motion between the horse-power and the thrasher.

Fig. 63.

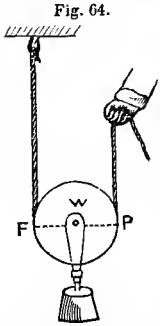
Universal joint.

SECTION V.

THE PULLEY.

LET a cord fixed at one end pass round a movable grooved wheel, and be grasped by the hand at the other end; then, in lifting any weight attached to the wheel, by drawing up the cord, the hand will move with twice the velocity of the weight. It will, therefore, exert double the degree of force. This operates precisely as a succession of levers of the second kind, the fixed cord being the fulcrum, and the cord drawn up by the hand the power. It thus constitutes one of the simplest kinds of the pulley, *Fig.* 64.

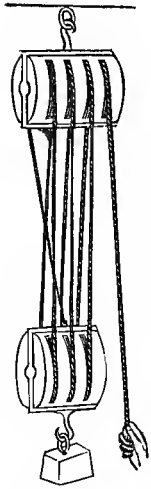
Fig. 64.



Pulley doubling the force.

The wheel is called a *sheave;* the term *pulley* is applied to the block and sheave; and a combination of sheaves, blocks, and ropes is called a *tackle.*

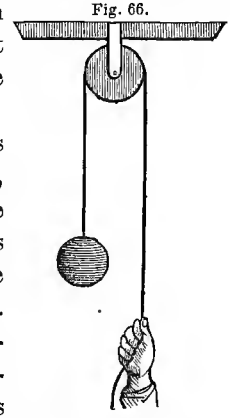
Fig. 65.



Pulley of six-fold power.

There are various combinations of single pulleys for increasing power, the most common of which, and least liable to become deranged by the cord being thrown off the wheels, is shown in *Fig.* 65. In this and in all similarly constructed pulleys, the weight is as many times greater than the power as the number of cords which support the lower block. If there be six cords, as in the figure, the weight will be six times the power.

Fig. 66.



Pulley with no increase of power.

Where a cord is passed over a single fixed wheel, as in *Fig.* 66, or over two or more wheels, as in *Fig.* 67, no power is gained, the moving force being the same in velocity as the weight. Such pulleys are sometimes, however, of use by altering the *direction* of the force. The latter is applied with advantage to unloading or pitching hay by means of a horse power, saving much time and labor, as shown in *Fig.* 67. The head of the fork (*Fig.* 68) is about 28 inches long, and is fitted with steel prongs 20 inches long. The rope attached at *a* passes over the pulley above, by which the

Fig. 67.

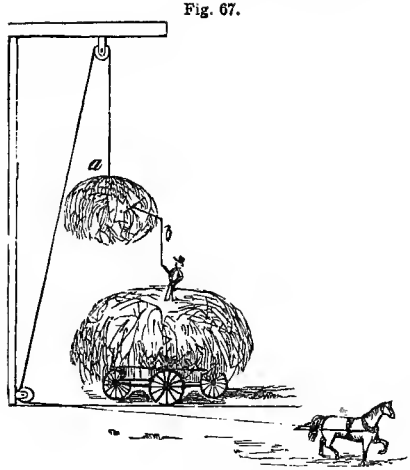
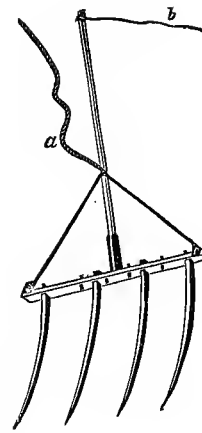


Fig. 68.



Pitching hay with horse-power.

fork, after being thrust into the hay, is lifted by the strength of the horse working just without the barn door. It is kept level by means of the rope, *b*, until the fork is high enough to unload, when this rope is slackened, and the hay deposited. The man on the mow can give any direction to the hay he pleases while it remains suspended. The horse is backed, and the operation repeated. The arrangement is cheap, and with it six tons have been pitched 20 feet high in an hour.

The usefulness of the pulley depends mainly upon its lightness and portable form, and the facility with which it may be made to operate in almost any situation. Hence it is much used in building, and is extensively applied in the rigging of ships. In the computation of its power there is a large drawback, not taken into account in the preceding calculation, which materially lessens its advantage; this is the friction of

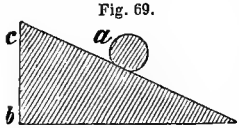
the wheels and blocks and the stiffness of the cordage, which are often so great that two thirds of the power is lost.

SECTION VI.

THE INCLINED PLANE.

THE *inclined plane* or slope possesses a power which is estimated by the proportion which its length bears to the height. If, for example, the plane be twice as long as the perpendicular height, then in rolling the body, *a*, up the inclined plane (*Fig.* 69), it will move through twice the distance required to lift it directly from *b* to *c*. Therefore only one half the strength else required need be exerted for this purpose. The same reasoning will apply to any other proportion between the height and length; that is, the more gradual or less steep the slope becomes, the greater will be the advantage gained. A familiar example occurs in lifting a loaded barrel into a wagon: the longer the plank used in rolling it, the less is the exertion needed.

Fig. 69.



A body, in rolling freely down an inclined plane, acquires the same velocity that it would attain if dropped perpendicularly from a height equal to the perpendicular height of the plane. Thus, if an inclined plane on a plank road be 100 yards long and 16 feet high, a freely running wagon, left to descend of its own accord, will move 32 feet per second by the time it reaches the bottom, that being the velocity of a stone falling 16 feet. Or, a rail-car on an inclined plane 145 feet

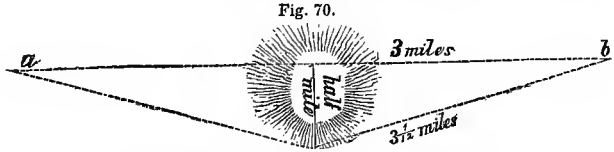
high will attain a speed of 96 feet per second, or more than 65 miles an hour, at the foot of the plane, which is equal to the velocity of a stone falling three seconds, or 145 feet.

ASCENT IN ROADS.

All roads not perfectly level may be regarded as inclined planes. By the application of the preceding rule, we may discover precisely how much strength is lost in drawing heavy wagons up hill. If the load and wagon weigh a ton, and the road rise one foot in height to every five feet of distance, then the increased strength required to draw the load will be one fifth of its weight, or equal to 400 pounds. If it rise only one foot in twenty, then the increase in power needed to ascend this plane will be only 100 pounds. The great importance of preserving as nearly as practicable a perfect level is very obvious.

There are many roads made in this country, rising over and descending hills, which might be made nearly level by deviating a little to the right or to the left. Suppose, for example, that a road be required to connect the two points *a* and *b* (*Fig.* 70), three miles

Fig. 70.



apart, but separated by a lofty hill midway between them, and one mile in diameter. Passing half a mile on either side would entirely avoid the hill, and the road thus curved would be only one hundred and forty-

eight yards, or one twelfth of a mile longer. The same steep hill is ascended perhaps fifty to five hundred times a year by a hundred different farmers, expending an amount of strength, in the aggregate, sufficient to elevate ten thousand tons annually to this height, as a calculation will at once show—more than enough for all the increased expense of making the road level.

It is interesting and important to examine how much further it is expedient to carry a road through a circuitous level course than over a hill. To ascertain this point, we must take into view the resistance occasioned by the rough surface or soft material of the road. Roads vary greatly in this particular, but the following may be considered as about a fair average. In drawing a ton weight (including wagon) on freely running wheels, on a perfect level, the strength exerted will be found about equal to the following:

On a hard, smooth plank road	40	pounds.
On a good Macadam road	60	"
On a common good hard road	100	"
On a soft road about	200	"

Now let us compare this resistance to the resistance of drawing up hill. First, for the plank road—forty pounds is one fiftieth of a ton; therefore a rise of one foot in fifty of length will increase the draught equal to the resistance of the road. Hence the road might be increased fifty feet in length to avoid an ascent of one foot; or, at the same rate, it might be increased a mile in length to avoid an ascent of one hundred and five feet. But in this estimate the increase in cost of making the longer road is not taken into account. If making and keeping in repair be equal to three hund-

red dollars yearly per mile, and one hundred teams pass over it daily, at a cost for traveling of four cents each per mile, being four dollars daily, or twelve hundred dollars per annum, then the cost of making and repair would be one quarter of the expense of traveling over it. Therefore the mile should be diminished one quarter in length to make these two sources of expense counterbalance each other. Hence a road with this amount of travel should, with a reference to public accommodation, be made three fourths of a mile longer to avoid a hill of one hundred and five feet. This estimate applies to loaded teams only. For light carriages the advantages of the level road would not be so great. One half to five eighths of a mile would, therefore, be a fair estimate for all kinds of traveling taken together.

The following table shows the rise in a mile of road for different ascents:

For a rise of	1	foot in	10,	the road ascends	528	feet per mile.
do.	1	do.	13,	do.	406	do.
do.	1	do.	15,	do.	352	do.
do.	1	do.	20,	do.	264	do.
do.	1	do.	25,	do.	211	do.
do.	1	do.	30,	do.	176	do.
do.	1	do.	35,	do.	151	do.
do.	1	do.	40,	do.	132	do.
do.	1	do.	45,	do.	117	do.
do.	1	do.	50,	do.	106	do.
do.	1	do.	100,	do.	53	do.
do.	1	do.	125,	do.	42	do.

The same kind of reasoning applied to a common good road will show that it will be profitable for the public to travel about half that distance to avoid a hill of one hundred and five feet. In this case the whole

yearly cost of the road, including interest on the land, and the cost of repairs, would not usually be more than a tenth part of the same cost for plank, or would not exceed thirty dollars.

On rail-roads, where the resistance is only about one fifth part of the resistance of plank roads, the disproportion between the draught on a level and up an ascent becomes many times greater. Thus, if a single engine will move three hundred and fifty tons on a level, then two engines will be required for an ascent of only twenty feet per mile, four engines for fifty feet per mile, and six engines for eighty feet per mile.

Such estimates as these merit the attention of the farmer in laying out his own private farm roads. It may be worthy of considerable effort to avoid a hill of ten or twenty feet, which must be passed over a hundred times yearly with loads of manure, grain, hay, and wood. The greatly-increased resistance of soft materials, also, is too rarely taken into account. A few loads of gravel, well applied, would often prevent ten times the labor in plowing through deep ruts, to say nothing of the breaking of harness and wagons by the excessive exertions of the team.

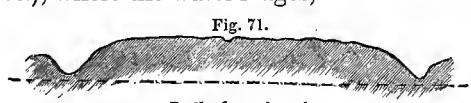
FORM AND MATERIALS FOR ROADS.

The depth of the mud in common roads is often unnecessarily great, in consequence of heaping together with the plow and scraper the soft top-soil for the raised carriage-way. When heavy rains fall, this forms a deep bed of mud, into which the wheels work their way, and cause extreme labor to the team. A much better way is to scrape off and cart away into the fields

adjoining all the soft, rich, upper surface, and then to form the harder subsoil into a slightly-rounded carriage-way, with a ditch on each side. Such roads as this have a very hard and firm foundation, and they have been found not to cut up into ruts, nor to form much mud, even in the wettest seasons. On this hard foundation six inches of gravel will endure longer and form a better surface than twelve inches on a raised "turnpike" of soft soil and mud.

It frequently happens that the form of the surface increases the quantity of mud in a road, by not allowing the water to flow off freely. The earth is heaped up in a high ridge, but having little slope on the top (*Fig.* 71), where the water lodges, and ruts are formed,

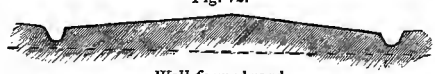
Fig. 71.



Badly-formed road.

the only dry portions being on the brink of the ditches, where the water can escape. Instead of this form, there should be a gradual inclination from the centre to the ditches, as shown in *Fig.* 72. This inclination

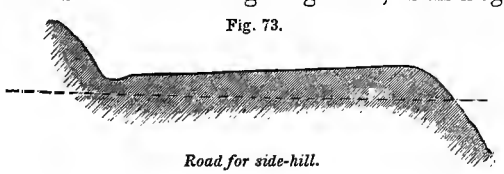
Fig. 72.



Well-formed road.

should not exceed 1 foot in 20. On hillsides the slope should all be toward the higher ground, as in *Fig.* 73.

Fig. 73.



Road for side-hill.

Hard and durable roads are made on the plan of Telford. Their foundation is rounded stones, placed upright, with the smaller or sharp ends upward. The smaller stones are placed near the sides, and the larger at the centre, thus giving to the road a convex form. The spaces are then filled in with small broken stone, and the whole covered with the same material or with gravel. The pressure of wagons crowds it compactly between the stones, and forms a very hard mass.

IMPORTANCE OF GOOD ROADS.

The principles of road-making should be better understood by the community at large. Farmers are deeply interested in good roads. Nearness to market, and facilities for all other kinds of communication, are worth a great deal, often materially affecting the price of land and its products. The difference between traveling ten miles through deep mud, at two miles per hour, with half a load, and traveling ten miles over a fine road, at five miles per hour, with a full load, should not be forgotten.

"In the absence of such facilities," says Gillespie, "the richest productions of nature waste on the spot of their growth. The luxuriant crops of our Western prairies are sometimes left to decay on the ground, because there are no rapid and easy means of conveying them to market. The rich mines in the northern part of the State of New York are comparatively valueless, because the roads among the mountains are so few and so bad, that the expense of the transportation of the metal would exceed its value. So, too, in Spain it has been known, after a succession of abundant har-

vests, that the wheat has actually been allowed to rot, because it would not repay the cost of carriage." Again, "When the Spanish government required a supply of grain to be transferred from Old Castile to Madrid, 30,000 horses and mules were necessary for the transportation of four hundred and eighty tons of wheat. Upon a broken-stone road of the best sort, *one hundredth* of that number could easily have done the work." He further adds, in speaking of the improvements in roads made by Marshal Wade in the Scottish Highlands, "His military road is said to have done more for the civilization of the Highlands than the preceding efforts of all the British monarchs. But the later roads, under the more scientific direction of Telford, produced a change in the state of the people which is probably unparalleled in the history of any country for the same space of time. Large crops of wheat now cover former wastes; farmers' houses and herds of cattle are now seen where was previously a desert; estates have increased seven-fold in value and annual returns; and the country has been advanced at least one hundred years."

SECTION VII.

THE WEDGE.

THE wedge is a double inclined plane, the power being applied at the back to urge it forward. It becomes more and more powerful as it is made more acute; but, on account of the enormous amount of friction, its exact power can not be very accurately estimated. It is nearly always urged by successive

blows of a heavy body, the momentum of which imparts to it great force.

All cutting and piercing instruments, as knives, scissors, chisels, pins, needles, and awls, are wedges. The degree of acuteness must be varied according to circumstances; knives, for instance, which act merely by pressure, may be made with a much sharper angle than axes, which strike a severe blow. For cutting very hard substances, as iron, the edge must be formed with a still more obtuse angle.

The utility of the wedge depends on the friction of its surfaces. In driving an iron wedge into a frozen or icy stick of wood, as every chopper has observed, the want of sufficient friction causes it immediately to recoil, unless it be previously heated in the fire. The efficacy of nails depends entirely on the friction against their wedge-like faces.

THE SCREW.

The screw may be regarded as nothing more than an inclined plane winding round the surface of a cylinder (*Fig.* 74). This may be easily understood by cutting a piece of paper in such a form that its edge, *a b* (*Fig.* 75), may represent the inclined plane; then, beginning at the wider end, and wrapping it about the cylindrical piece of wood, *c*, the upper edge of the paper will represent the thread of the screw.

Fig. 74.

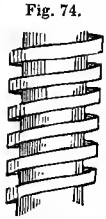
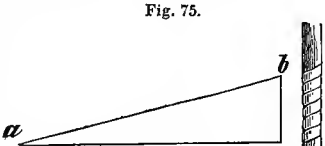


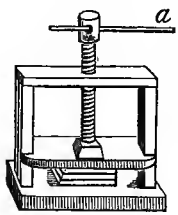
Fig. 75.



Although the friction attending the use of the screw

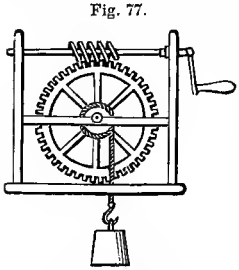
is considerable, and without it it would not retain its place, yet the slope of its inclined thread being so gradual, it possesses great power. This power is multiplied to a still greater degree by the lever which is usually employed to drive it, *a* (*Fig.* 76). If, for example, a screw be ten inches in circumference, and its threads half an inch apart, it exerts a force twenty times as great as the moving power. If it be moved by a lever twenty times as long as the diameter of the screw, here is another increase of twenty times in force. Multiplying 20 by 20 gives 400, the whole amount gained by this combination, and by which a man applying one hundred pounds in force could exert a pressure equal to twenty tons. About one third or one fourth of this should, however, be deducted for friction.

Fig. 76.



Screw and lever combined.

Fig. 77.



Screw, lever, and wheel combined.

When the screw is combined with the wheel and axle (*Figure* 77), it is capable of exerting great power, which may be readily calculated by multiplying the power of the screw and its lever into the power of the wheel and axle.

CHAPTER V.

APPLICATION OF MECHANICAL PRINCIPLES IN THE STRUCTURE OF THE PARTS OF IMPLEMENTS AND MACHINES.

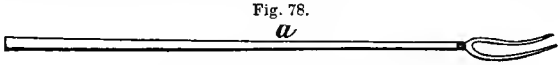
In contriving the more difficult and complex machines, the principles of mechanics must be closely studied, to give every part just that degree of strength required, and to render their operation as perfect as possible. But in making the more common and simple implements of the farmer, mere guess-work too often becomes the only guide. Yet it is highly useful to apply scientific knowledge even in the shaping of a hoe-handle or a plow-beam.

The simplest tool, if constantly used, should be formed with a view to the best application of strength. The laborer who makes with a common hoe two thousand strokes an hour, should not wield a needless ounce. If any part is heavier than necessary, even to the amount of half an ounce only, he must repeatedly and continually lift this half ounce, so that the whole strength thus spent would be equal, in a day, to twelve hundred and fifty pounds, which ought to be exerted in stirring the soil and destroying weeds. Or, take another instance: A farm wagon usually weighs nearly half a ton; many might be reduced fifty pounds in weight by proportioning every part exactly to the strength required. How much, then, should we gain here? Every farmer who drives a wagon with its

needless fifty pounds, on an average of only five miles a day, draws an unnecessary weight every year equal to the conveyance of a heavy wagon-load to a distance of forty miles.

Now a knowledge of mechanical science will often enable the farmer, when he selects and buys his implements, to judge correctly whether every part is properly adapted to the required strength. We shall suppose, for instance, that he intends to purchase a common pitchfork. He finds them differently formed, although all are made of the best materials. The handles of some are of equal size throughout. Some are smaller near the fork, as in *Fig.* 78, and others are

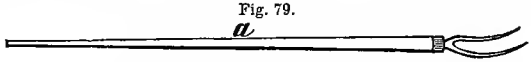
Fig. 78.



Badly-formed fork handle.

larger at the same place, as in *Fig.* 79. Now, if he

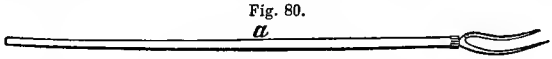
Fig. 79.



Badly-formed fork handle.

understands the principle of the lever, he knows that both of these are wrongly made, for the right hand placed at *a* is the fulcrum, where the greatest strength is needed, and therefore the one represented by *Fig.* 80

Fig. 80.

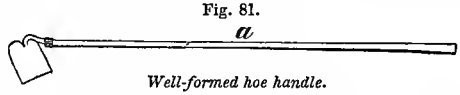


Well-formed fork handle.

is both stronger and lighter than the others. Again, *hoe handles*, not needing much strength, chiefly require lightness and convenience for grasping. Hence, in selecting from two such as are represented in the

annexed figures, the one should be chosen which is lightest near the blade, nearly all the motion being in that direction, because the upper end is the *centre* of motion. The right hand, at *a*, acting partly as the fulcrum, the hoe handle should be slightly enlarged at that place. *Fig.* 81 represents a well-formed handle,

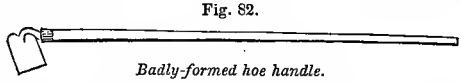
Fig. 81.



Well-formed hoe handle.

Fig. 82 a clumsy one. Rake handles should be made

Fig. 82.



Badly-formed hoe handle.

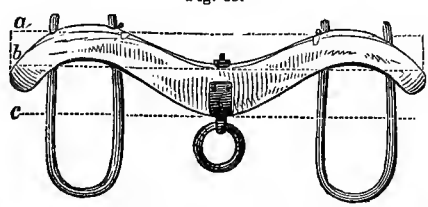
largest at the middle, or where the right hand presses. Rake-heads should be much larger at the centre, and tapering to the ends, where the stress is least, the two parts operating as two distinct levers, acting from the middle. *Horse-rakes* might be made considerably lighter than they usually are by observing the same principles. The greatest strength required for *plow-beams* is at the junction with the mould-board, and the least near the forward end, or furthest from the fulcrum or centre of motion.

Now it may be that the farmer who has had much experience may be able to judge of all these things without a knowledge of the science. But this scientific knowledge would serve to strengthen his experience, and enable him to judge more accurately and understandingly by showing him the reasons; and in many cases, where *new* implements were introduced, he might be enabled to form a good judgment before

he had incurred all the expense and losses of unsuccessful trials.

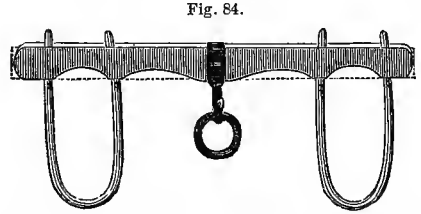
Even so simple a form as that of an ox-yoke is often made unnecessarily heavy. *Fig.* 83 represents one

Fig. 83.



that is faulty in this respect, by having been cut from a piece of timber as wide as the dotted lines *a c*, and being thus weakened, it requires to be correspondingly large. *Fig.* 84 is equally strong, much lighter, and is

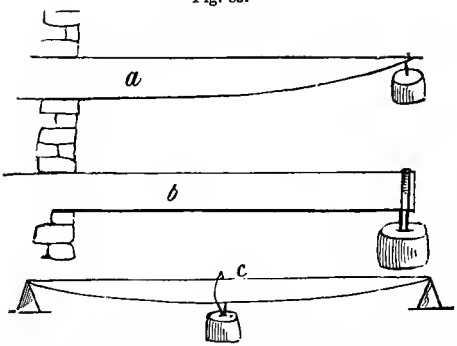
Fig. 84.



easily made from a stick of timber only as wide as *a b* in the former figure.

In the heavier machines, it is necessary to know the degree of taper in the different parts with accuracy. A thorough knowledge of science is needed to calculate this with precision, but a superficial idea may be given by figures. If a bar of wood, formed as in *a* (*Fig.* 85, p. 100), be fixed in a wall of masonry, it will possess as much strength to support a weight hung on the end as if it were the same size throughout, as *b*.

Fig. 85.



The first is equally strong with the second, and much lighter.* The same form doubled must be given if the bar is supported at the middle, with a weight at each end, or with the weight at the middle, supported at each end, as *c*. This form, therefore, is a proper one for many parts of implements, as the bars of whipple trees, the rounds of ladders, string-pieces of bridges, and any cross-beams for supporting weights. One half of this form, as *a*, is the proper form for rake-teeth, wheel-barrow handles, spade handles, &c. On fence-posts, the pressure being nearly alike on all parts, they should be nearly in the form of a wedge. Therefore a post of equal size throughout contains nearly twice as much timber as is needed for strength only.

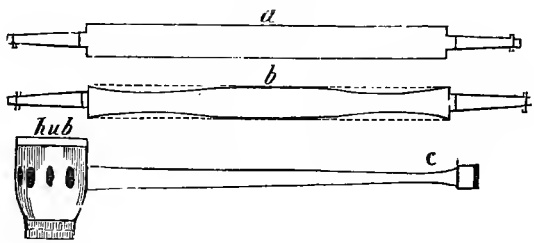
The form of these parts must, however, be modified to suit circumstances; as whipple-trees must be large enough at the ends to receive the iron hooks, wagon-

* The simple style of this work precludes an explanation of the mode of calculation for determining the exact form. Where the stick tapers only on one side, it is a common parabola; if on all sides, a cubic parabola.

tongues for ironing at the end, and spade handles for the easy grasp of the hand.

The axle-trees of wagons must be made not only strong in the middle, or at centre of pressure, but also at the entrance of the hub; because the wheels, when thrown sideways in a rut, or on a sideling road, operate as levers at that point. *a* and *b* (*Fig.* 86), show the manner in which the axles of carts may be rendered lighter without lessening the strength, *a* being the common form, and *b* the improved one.

Fig. 86.



Sometimes several forces act at once on different parts. For example, the spokes of wagon-wheels require strength at the hub for stiffening the wheel; they must be strong in the middle to prevent bending, and large enough at the outer ends, where they are soonest weakened by decay. Hence there should be nearly a uniform taper, slightly larger at the middle, and with an enlargement at the outer end, as *c* (*Fig.* 86).

A very useful rule in practice, in giving strength to structures, is this: the strength of every square beam or stick to support a weight increases exactly as the width increases, and also exactly as the *square of the depth* increases. For example, a stick of timber eight

inches wide and four inches deep (that is, four inches thick), is exactly twice as strong as another only four inches wide, and with the same depth. It is twice as wide, and consequently twice as strong; that is, its strength increases just as the width increases, according to the rule given. But where one stick of timber is twice as *deep*, the width being the same, it is *four times* stronger; if three times as deep, it is *nine times* stronger, and so on. Its strength increases as the *square* of the depth, as already stated. The same rule will show that a board an inch thick and twelve inches wide will be twelve times as strong when edgewise as when lying flat. Hence the increase in strength given to whippletrees, fence-posts, joists, rafters, and string-pieces to farm-bridges, by making them narrow and deep.

Again, the strength of a *round* stick increases as the cube of the diameter increases; that is, a round piece of wood three inches in diameter is eight times as strong as one an inch and a half in diameter, and twenty-seven times as strong as one an inch in diameter. This rule shows that a fork handle an inch and a half in diameter at the middle is as much stronger than one an inch and a quarter in diameter, as seven is greater than four. Now this rule would enable the farmer to ascertain this without breaking half a dozen fork handles in trying the experiment, and it would enable the manufacturer to know, without the labor of trying many experiments, that if he makes a fork handle an inch and a half at the middle, tapering a quarter of an inch toward the ends, it will enable the workman to lift with it nearly twice as much hay as with one an inch and a quarter only through its whole length.

CHAPTER VI.

FRICTION.

SECTION I.

The subject of friction has been postponed, or has been merely alluded to, in treating heretofore of machines, to prevent the confusion of considering too many things at once. As it has often an important influence on the action of machines, it is worthy of careful investigation.

It is familiar to most persons, that when two surfaces slide over each other while pressing together, the minute unevenness or roughness of their surfaces causes some obstruction, and more or less force is required. This resistance is known as *friction.*

ROLLING FRICTION.

The term is also applied to the resistance of one body *rolling over* another. This may be observed in various degrees by rolling an ivory ball successively over a carpet, a smooth floor, and a sheet of ice; the same force which would impel it only a few feet on the carpet, would cause it to move as many yards on a bare floor, and a still greater distance on the ice. The two extremes may be seen by the force required to draw a carriage on a deep sandy or loose-gravel road, and on a rail-road.

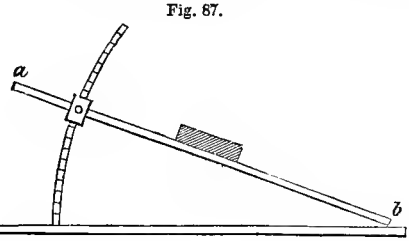
NATURE OF FRICTION.

If two stiff bristle brushes be pressed with their faces together, they become mutually interlocked, so that it will be quite difficult to give them a sliding motion. This may be considered as an extreme case of friction, and serves to show its nature. In two pieces of coarse, rough sandstone, or of roughly-sawed wood, asperities interlock in the same way, but less in degree; a diminished force is consequently required in moving the two surfaces against each other. On smoothly-planed wood the friction is still less; and on polished glass, where the unevenness can not be detected without the aid of a powerful magnifying glass, it is reduced still further in degree.

ESTIMATING THE AMOUNT OF FRICTION.

In order to determine the exact amount of friction between different substances, the following simple and ingenious contrivance is adopted: an inclined plane, *a b* (*Fig.* 87), is so formed that it may be raised to any

Fig. 87.



desired height by means of the arc of a circle and a screw. Lay a flat surface of the substance we wish to examine upon this inclined plane, and another small-

er piece or block of the same substance upon this surface; then raise the plane until it becomes just steep enough for the block to slide down by its weight. Now, by measuring the degree of slope, we know at once the amount of friction. Suppose, for example, the two surfaces be smoothly-planed wood: it will be found that the plane must be elevated about half as high as its length; therefore we know, by the properties of the inclined plane, heretofore explained, that it requires a force equal to one half the weight of the wooden block to slide it over a smooth wooden surface. Some kinds of wood have more friction than others, but this is about the average.

From the result of this experiment we may learn that to slide any object of wood across a floor requires an amount of strength equal to one half the weight of the object. A heavy box, for instance, weighing two hundred pounds, can not be moved without a force equal to one hundred pounds. It also shows the impropriety of placing a heavy load upon a sled in winter for crossing a bare wooden bridge or a dry barn floor, the friction between cast-iron sleigh-shoes and rough sanded plank being nearly equal to one third of the whole weight.* Hence a load of one ton (including the sled) would require a draught equal to more than six hundred pounds, which is too much for an ordinary single team. On bare unfrozen ground the friction would be still greater. On a plank bridge, with runners wholly of wood, it would be equal to half the load. All these facts may be readily proved by actually

* On clean hard wood, with polished metallic shoes, the friction would be much less, or a fourth, or fifth.

placing the sled on slopes of plank and of earth, and by observing the degree of steepness required for sliding down by its own weight.

In a similar way, we are enabled easily to ascertain the force required to draw a wagon upon any kind of level surface. Suppose, for example, that we wish to determine the precise amount of force for a wagon weighing, with its load, one ton, on a plank road. Select some slight descent, where the wagon will barely run with its own weight. Ascertain by a *level* just what the degree of descent is; then divide the weight of the wagon by the degree of the slope, and we shall have the force sought for. To make this rule plainer by an example: it will be found that a good, newly-laid plank track, if it possess a descent of only one foot in fifty feet distance, will be sufficient to give motion to an easy-running wagon; therefore we know that the strength required to draw it on a level will be only one fiftieth part of a ton, or forty pounds.

The resistance offered to the motion of a wagon by a Macadam road, by a common dry road, and by one with six inches of mud, may be readily determined in the same way by selecting proper slopes for the experiment. If by such trials as these the farmer ascertains the fact that a few inches of mud are sufficient to retard his wagon so much that it will not run of its own weight down a slope of one foot in four (and few common roads are ever steeper), then he may know that a force equal to one fourth the whole weight of his wagon and load will be required to draw it on a level over a similar road—that is, the enormous force of five hundred pounds will be needed for one ton, of

which many wagons will constitute nearly one half. Hence he can not fail to see the great importance, for the sake of economy, and humanity to his team, of providing roads, whether public or private, of the hardest and best materials.

SECTION II.

RESULTS WITH THE DYNAMOMETER.

ANOTHER mode of determining the resistance of roads is by means of the *Dynamometer*.* It resembles a *spring-balance*, and one end is fastened to the wagon and the other end connected with the horses. The force applied is measured on a graduated scale, in the same way that the weight of any substance is measured with the spring-balance. A more particular description of this instrument will be given hereafter.

Careful experiments have been made with the dynamometer to ascertain accurately the resistance of various kinds of roads. The following are some of the results:

On a new gravel road, a horse will draw eight times as much as the force applied; that is, if he exerts a force equal to one hundred and twenty-five pounds, he will draw half a ton on such a road, including the weight of the wagon, *the road being perfectly level.*

On a common road of sand and gravel, sixteen times as much, or one ton.

On the best hard-earth road, twenty-five times as much, or one and a half tons.

On a common broken-stone road, twenty-five to thir-

* From two Greek words, *dunamis*, power, and *metreo*, to measure.

ty-six times as much, or one and a half to two and a quarter tons.

On the best broken-stone road, fifty to sixty-seven times as much, or three to four tons.

On a common plank-road, clean, fifty times as much, or three tons.

On a common plank-road, covered thinly with sand or earth, thirty to thirty-five times as much, or about two tons.

On the smoothest oak plank-road, seventy to one hundred times as much, or four and a half to six tons.

On a highly-finished stone track-way, one hundred and seventy times as much, or ten and a half tons.

On the best rail-road, two hundred and eighty times as much, or seventeen and a half tons.

The firmness of surface given to a broken-stone road by a paved foundation was found to lessen the resistance about one third.

On a broken-stone road it was found that a horse could draw only about two thirds as much when it was moist or dusty as when dry and smooth; and when muddy, not one half as much. When the mud was thick, only about one quarter as much.

The character of the vehicle has an influence on the draught. Thus, a cart, a part of the load of which is supported by the horse, usually requires only about two thirds the force of horizontal draught needed for wagons and carriages. On rough roads the resistance is slightly diminished by springs.

On soft roads, as earth, sand, or gravel, the number of pounds draught is but little affected by the speed; that is, the resistance is no greater in driving on a trot

than on a walk; but on hard roads it becomes greater as the velocity increases. Thus a carriage on a dry pavement requires one half greater force when the horses are on a trot than on a walk; but on a muddy road the difference between the two rates of speed is only about one sixth. On a rail-road, where a draught of ten pounds will draw a ton ten miles an hour, the resistance increases so much at a high degree of speed as to require a force of fifty pounds per ton at sixty miles an hour—that is, it would require five times as much actual power to draw a train one hundred miles at the latter rate as at the former; but as the speed is six times as great, the actual force *during a given time* would be five times six, or thirty times as great.

WIDTH OF WHEELS.

Wheels with wide tire run more easily than narrow tire, on soft roads; on hard, smooth roads, there is no sensible difference. Wide tire is most advantageous on gravel and new broken-stone roads, both by causing the vehicles to run more easily, and by improving the surface. For the latter reason, the New York turnpike law allows six-inch wheels to pass at half price, and twelve-inch wheels to pass free of toll. Wheels with broad tire on a farm would pass over clods, and not sink between them; or would only press the surface of new meadows, without cutting the turf. But where the ground becomes muddy, the mud closes on both sides of the rim, and loads the wheels. On clayey soils, narrow tire unfits the roads for broad wheels. For these reasons, broad wheels are decidedly objectionable for clayey or soft soils, and they are chiefly to be

recommended for broken-stone roads, and gravelly, or dry, sandy localities. They are also much the best for the wheels of sowing or drilling machines, which only pass over mellowed surfaces.

The larger the wheels are made, the more easily they run; thus a wheel six feet in diameter meets with only half the resistance of a wheel three feet in diameter.

A flat piece of wood, sliding on one of its broad surfaces, is subject to the same amount of friction as when sliding upon its edge. Hence the friction is the same, provided the pressure be the same, whether the surface be small or large.* Or, in other words, if the surfaces are the same, a double pressure produces a double amount of friction; a triple pressure, a triple amount, and so on.

A narrow *sleigh-shoe* usually runs with least force, for two reasons: first, its forward part cuts with less resistance through the snow; and, secondly, less force is required to pack the narrow track of snow beneath it. The only instance in which a wide sleigh-shoe would be best, is where a crust exists that would bear it up, and through which a narrow one would cut and sink down.

VELOCITY.

Friction is entirely independent of velocity; that is, if a force of ten pounds is required to turn a carriage wheel, this force will be ten pounds, whether the carriage is driven one or five miles per hour. Of course, it will require five times as much force to draw five

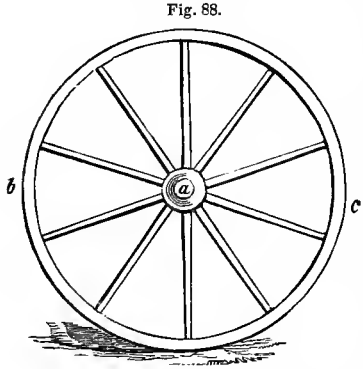
* Generally speaking, this is very nearly correct; but when the pressure is intense, the friction is slightly less on the smaller surface.

miles per hour, because five times the distance is gone over; but, measured by a dynamometer or spring-balance, the pressure would be the same. In precisely the same way, the weight of a stone remains the same, whether lifted slowly or quickly by a lever. If the friction of the wheels of a wagon on their axles be equal to ten pounds, driving the horse fast or slowly will not increase or diminish it. But fast driving will require more strength, for the same reason that a man would need more strength to carry a bag of wheat up two flights of stairs than one, in one minute of time.

FRICTION AT THE AXLE.

A carriage wheel, or any other wheel revolving on an axle, will run more easily as the axle is made smaller. This is not owing to the rubbing surfaces being less in size, as some mistakenly suppose, for it has just been shown that this makes very little or no difference, provided the pressure is the same; but it is owing to the leverage of the wheel on the friction at the axis; and the smaller the axle, the greater is this leverage; for, if the axle, *a* (*Figure* 88), be six inches in circumference, and the wheel, *b c*, be ten feet in circumference, then the outer part of the wheel will move twenty times further than the part next the axle.

Fig. 88.



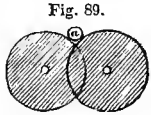
Therefore, according to the rule of virtual velocities, one ounce of force at the rim of the wheel will overcome twenty ounces of friction at the axle; or if the axle were twice as large, then, according to the same rule, it would require two ounces to overcome the same friction acting between larger surfaces.

For this reason, large wheels in wheel-work for multiplying motion, if not made too heavy, run with less force than smaller ones, the power acting upon a larger lever. Horse-powers for thrashing-machines, consisting chiefly of a large, light crown-wheel, well stiffened by brace-work, have been found to run with remarkable ease; a good example of which exists in what is known as *Talpin's* horse-power, when made in the best manner.

FRICTION-WHEELS.

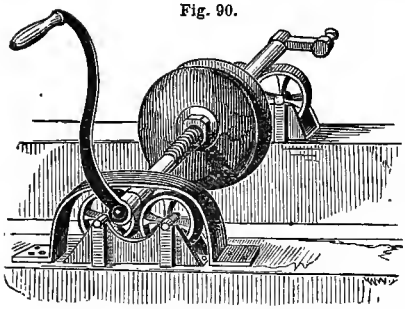
On the preceding principle, *friction-wheels* or *friction-rollers* are constructed, for lessening as much as possible the friction of axles in certain cases. By this contrivance, the axle, *a* (*Fig.* 89), instead of revolving in a simple hole or cavity, rests on or between the edges of two other wheels. As the axle revolves, the edges turn with it, and the rubbing of surfaces is only at the axles of these two wheels. If, therefore, these axles be twenty times smaller than the wheels, the friction will be only one twentieth the amount without them. This contrivance has been strongly recommended and considerably used for the cranks of grindstones (*Fig.* 90), but it was not found to answer the intended purpose so well as was expect-

Fig. 89.



Friction-wheels.

Fig. 90.



Grindstone on Friction-wheels.

ed, for the very plain reason that, in using a grindstone, nearly all the friction is at the circumference, or between the stone and the tool, which friction-wheels could not, of course, remove.

SECTION III.

LUBRICATING SUBSTANCES.

LUBRICATING substances, as oil, lard, and tallow, applied to rubbing surfaces, greatly lessen the amount of friction, partly by filling the minute cavities, and partly by separating the surfaces. In ordinary cases, or where the machinery is simple, those substances are best for this purpose which keep their places best. Finely-powdered black-lead, mixed with lard, is for this reason better for greasing carriage wheels than some other applications. Drying oils, as linseed, soon become stiff by drying, and are of little service. Olive oil, on the contrary, and some animal oils, which scarcely dry at all, are generally preferred. To obtain the full benefit of oil, the application must be frequent.

According to the experiments made with great care by Morin, at Paris, the friction of wooden surfaces on wooden surfaces is from one quarter to one half the force applied; and the friction of metals on metals, one

fifth to one seventh—varying in both cases with the kinds used. Wood on wood was diminished by lard to about one fifth to one seventh of what it was before; and the friction of metal on metal was diminished to about half what it was before; that is, the friction became about the same in both cases after the lard was applied.

To lessen the friction of wooden surfaces, lard is better than tallow by about one eighth or one seventh; and tallow is better than dry soap about as two is to one. For iron on wood, tallow is better than dry soap about as five is to two. For cast iron on cast iron, polished, the friction with the different lubricating substances is as follows:

Water	31
Soap	20
Tallow	10
Lard	7
Olive oil	6
Lard and black-lead	5

When bronze rubs on wrought iron, the friction with lard and black-lead is rather more than with tallow, and about one fifth more than with olive oil. With steel on bronze, the friction with tallow and with olive oil is about one seventh less than with lard and black-lead.

As a general rule, there is least friction with lard when hard wood rubs on hard wood; with oil, when metal rubs on wood, or metal on metal—being about the same in each of all these instances.

In simple cases, as with carts and wagons, where the friction at the axle is but a small portion of the re-

sistance,* a slight variation in the effects in the lubricating substance is of less importance than retaining its place. In more complex machinery, as horse-powers for thrashing-machines, friction becomes a very large item, unless the parts are kept well lubricated with the best materials.

Leather and hemp bands, when used on drums for wheel-work, should possess as much friction as possible, to prevent slipping, thus avoiding the necessity of tightening them so much as to increase the friction of the axles. Wood with a rough surface has one half more friction than when worn smooth; hence moistening and rasping small drums may be useful. Facing with buff leather or with coarse thick cloth also accomplishes a useful purpose. It often happens that wetting or oiling bands will prevent slipping, by keeping their surfaces soft, and causing them to fit more closely the rough surface of the drum.

ADVANTAGES OF FRICTION.

Although friction is often a serious inconvenience, or loss, in lessening the force of machines, there are many instances in which it performs important offices in nature and in works of art. "Were there no friction, all bodies on the surface of the earth would be clashing against each other; rivers would dash with an unbounded velocity, and we should see little besides col-

* If the friction at the axle be one twelfth of the force, and the diameter of the wheels ten times as great as the diameter of the axle, the friction at the axles will be reduced to one twelfth of a tenth, or one hundred and twentieth part of the force, according to the law of virtual velocities as applied to the wheel and axle.

lision and motion. At present, whenever a body acquires a great velocity, it soon loses it by friction against the surface of the earth. The friction of water against the surfaces it runs over soon reduces the rapid torrent to a gentle stream; the fury of the tempest is lessened by the friction of the air on the face of the earth, and the violence of the ocean is subdued by the attrition of its own waters.

"Its offices in the works of art are equally important. Our garments owe their strength to friction, and the strength of ropes depends on the same cause; for they are made of short fibres pressed together by twisting, causing a sufficient degree of friction to prevent the sliding of the fibres. Without friction, the short fibres of cotton could never have been made into such an infinite variety of forms as they have received from the hands of ingenious workmen."* Deprived of this retaining force, the parts of stone walls, piles of wood and lumber, and the loads of carts and wagons, as well as the wheels themselves, would slide without restraint, as if their surfaces were of the most icy smoothness, and walking without support would be impossible.

The tractive power of locomotives depends on the friction between the wheels and iron rails, which is equal to about one fifth of the weight of the engine; that is, a locomotive weighing twenty-five tons will draw with a force of five tons, without producing slipping of the wheels.

* Encyclopædia Americana.

SECTION IV.

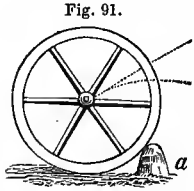
PRINCIPLES OF DRAUGHT.

An examination of the nature or laws of friction enables us to ascertain the best line of draught for teams when attached to wagons and carriages. If there were no friction whatever upon the road, the best direction for the traces would be parallel to the road, that is, on a level with the wagon; but as there is always some friction, the line of draught should be a little rising, so as to tend to lessen the pressure of the wheels on the road.

Now this upward direction of the draught *should always be exactly of such a slope, that if the same slope were given to the road, the wagon would just descend by its weight.* The more rough or muddy the road is, the steeper should be this line of draught or direction of the traces.* On a good common road it would be much less, and on a plank road but slightly varied from a horizontal direction. On a rail-road the line should be about level. On good sleighing, some of the strength of the team is commonly lost by too steep a line of draught.

The reason of this rule may be understood by the following explanation: Let the obstruction, *a*, in the annexed figure (*Fig.* 91), represent the friction the wheel constantly meets with in rolling over a common road. To overcome this friction, the wheel must

Fig. 91.



* Provided the wheels are not made smaller for this purpose, increasing their resistance.

rise in the direction of the dotted line. Therefore, if the force is made to pull in this direction, it will act more advantageously than in any other, because this is the course in which the centre of the wheel must move. Now if a downward slope were given to the road at this obstruction, the wheel and the obstruction would be brought both on a level, and the wheel would move with the slightest degree of force.

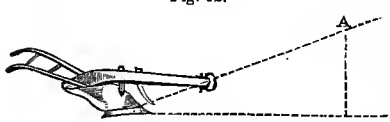
It will be understood from the preceding rule that a sled running on bare ground should be drawn by traces bearing upward in a large degree. The same remark will apply to the plow, which slides upon the ground in a similar way, with the pressure of the turning sod as a load. Hence the reason that a great saving of strength results from the use of short traces in plowing. An experiment was tried for the purpose of testing this reasoning; first, with traces of such length that the horses' shoulders were about ten feet from the point of the plow; and secondly, with the distance increased to about fifteen feet. With the short traces a strength was required equal to $2\frac{1}{4}$ cwt., but with the long traces it amounted to $3\frac{1}{2}$ cwt.

But the draught-traces may be made too short. When this is the case, the plow is necessarily thrown too much upon its point to keep it from flying out of the ground, by which means it works badly in turning the furrow. In addition to this evil, the plowman is compelled to bear down heavily, adding to the friction of the sole on the bottom of the furrow, and greatly increasing his labor.

The line of draught should be so adjusted that the plow may press equally all along on its sole or bottom,

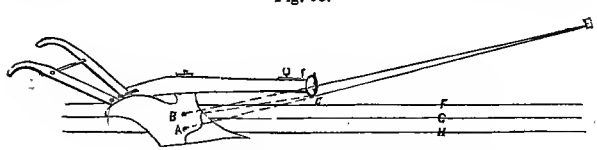
which will cause it to run evenly and with a steady motion. This end will be effected by giving the traces or draught-chain just such a length that the share of the plow (or centre of resistance), the clevis, and the point of draught at the horses' shoulders (or the ring of the ox-yoke) shall all form a straight line. This is shown in the annexed figure, where A is the place of the ox-ring or of the forward extremity of the traces (*Figure* 92).

Fig. 92.



The centre of resistance will vary with the depth of plowing. When the furrow is shallow (as shown by the lines G H, *Fig.* 93), the centre of resistance will be at A, requiring the

Fig. 93.



Line of draught for the plow.

team to be fastened to the lower side of the clevis, C; but when the depth is greater (as shown by F H), the centre of resistance will be at B, requiring a higher attachment to the clevis; the point of draught, E, remaining the same in both cases.

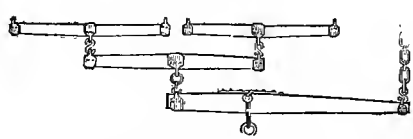
So great is the difference between an awkward and skillful adjustment of the draught to the plow, that some workmen with a poor instrument have succeeded better than others with the best; and plows of second quality have sometimes, for this reason, been preferred to those of the most perfect construction.

COMBINED DRAUGHT OF ANIMALS.

When several animals are combined together, it is of great importance that they should be exactly matched in gait. Much force is often wasted when they draw unsteadily or unevenly. It is more difficult to divide the draught equally among several animals when placed one before the other, or *ad tandem*, than when arrayed abreast, for some may hang back, and others do more than their share, unless a skillful driver is always on the watch. It also happens, when thus arranged, that the forward horses draw horizontally, while the hindmost one draws in a sloping line, and the line of draught between them thus being crooked, more or less force is lost. This may be, however, remedied in part by placing the taller animals forward, and the smaller behind.

For these reasons, when only three horses are used, they should always be placed abreast. The force required for each may be rendered exactly equal by the whipple-trees usually employed for this purpose, and represented in *Fig.* 94, where two horses are attached

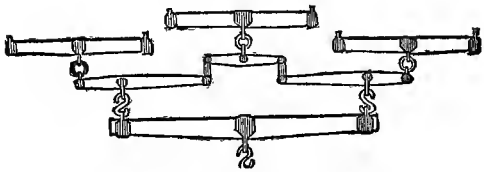
Fig. 94.



Whipple-tree for three horses.

to the shorter end, and the third to the longer end of the common bar. Another ingenious but more complex arrangement is shown by *Fig.* 95, where also the central horse has only half the two others, by being

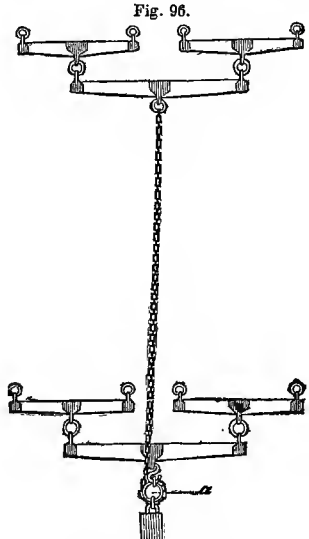
Fig. 95.



Whipple-tree for three horses.

attached to the longer ends of the intermediate bars. *Fig.* 96 represents the mode of attaching four horses in draught, their force being equalized by passing the

Fig. 96.



Whipple-tree for four horses.

chain round the wheel in the pulley-block, *a*, security being provided that the hindmost pair shall not encroach on the forward pair, by connecting the end of the chain at the same time to the plow.

SECTION V.

CONSTRUCTION AND USE OF THE DYNAMOMETER.

THE dynamometer, or force-measurer, has been already briefly alluded to, but a more particular description will be useful. In the construction and selection of all machines and implements that require much power in their use, the dynamometer is indispensable, although at present but little known. As an example of its utility, the farmer may wish to choose between two plows which, so far as he can perceive, may do their work equally well; but this instrument, when applied, may show that the team must draw with a force equal to 400 pounds in moving one of them through the soil, while 300 pounds would be sufficient for the other. He would, therefore, select the one of easiest draught, and by doing so would save the labor of one day in four to his team, or twenty-five days in a hundred, which would be worth many times the cost of the trial. The same advantage might be derived in the selection of harrows, cultivators, horse-rakes, straw-cutters, and all other implements drawn by horses or worked by men. Again, the farmer may be in doubt in choosing between two thrashing-machines, which in other respects may work equally fast and well; but the dynamometer may show that one requires a severer exertion from the team, and consequently is less valuable for use.

The operation of this instrument may be readily understood by *Figure* 97, where *b* represents the dynamometer, made precisely similar to a large and stiff

Fig. 97.

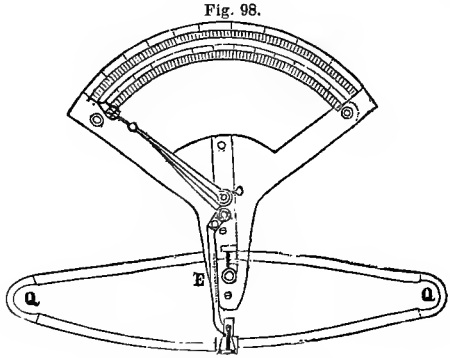
Dynamometer, or Force-measurer.

spring balance, with one hook attached to the plow and the other to the whipple-tree. The amount of force required to draw the plow is accurately measured on the scale by the index or pointer, *a*.

Sometimes the motion of this index is multiplied, or made greater and more easily seen, by means of a cog-wheel and rack-work; but this renders the instrument, at the same time, more complex.

Another form of this instrument is shown in *Fig.* 98,

Fig. 98.

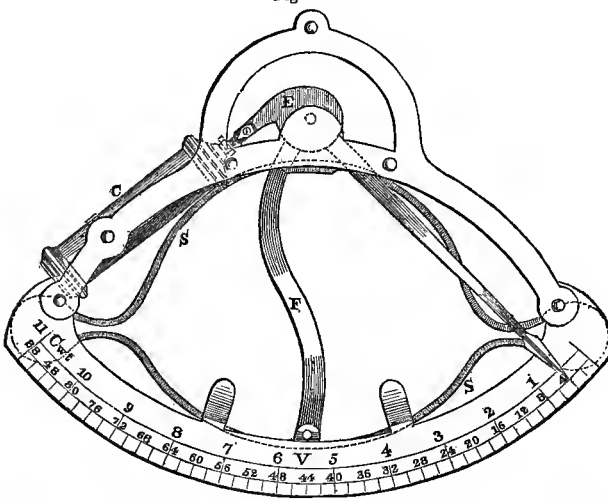


Elliptic Dynamometer.

where the ends of the oval spring, Q Q, are attached to the plow and draught. The harder the force exerted by the team, the closer together will the sides of this spring be brought, causing the rod, E, to press against the index or pointer, and showing the precise degree of force on the circular scale.

An improvement, by rendering the instrument more compact, is shown in *Fig.* 99, where S S is the spring, and directly over it is the graduated scale.

Fig. 99.



Elliptic Dynamometer, in compact form: S S, *spring;* F, *cross-lever for moving index.*

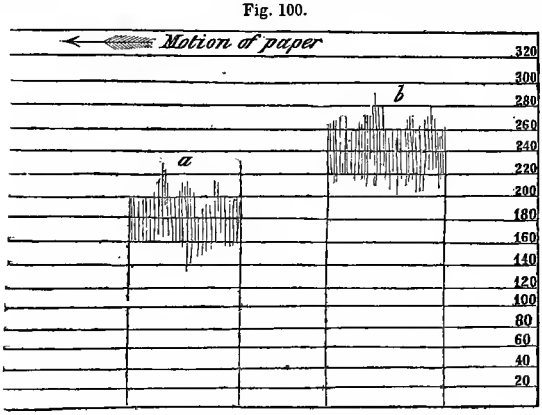
An inconvenience occurs in the use of the instruments now described from the rapid vibration of the index, resulting from the quick changes in the force, partly from inequalities in the soil, and partly from the unsteady motion of the horses. The vibration is sometimes so great that the index can be hardly seen, rendering it difficult to measure the average force. This inconvenience has been removed, in a great degree, by attaching to one end of the index, E (*Fig.* 99), a piston working in a cylinder filled with oil, C; this piston has a small hole through it, through which the oil pass-

es from one side to the other as the draught varies, but not fast enough to allow any sudden motion.

SELF-RECORDING DYNAMOMETER.

A less simple but more perfect instrument is the *Self-recording Dynamometer*, which marks accurately all the vibrations on a slip of paper while the plow is in operation. A pencil is fixed to the index, and presses, by means of a spring, against the paper, thus giving a true register of the force exerted. To prevent the pencil from constantly marking on the same line, the paper is made to move slowly in a side direction, so that all the vibrations are shown, as represented in *Fig.* 100,

Fig. 100.

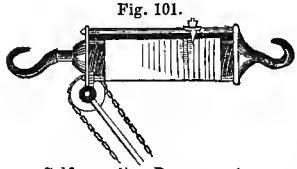


The markings of the Self-recording Dynamometer.

and they may be accurately examined and read off at leisure, *a* and *b* representing the forces of two different plows, drawn through a single furrow across the field. The motion of the paper is effected by being placed on two rollers, one of which unwinds it from the other.

This roller is made to turn by means of a wheel running on the ground, which gives motion to the roller through an endless chain, working a cog-wheel by means of an endless screw. The cylindrical dynamometer, shown in *Fig.* 101, is used for this purpose, lengthwise upon which the two rollers are placed for holding the paper. With this instrument a permanent register might be made of the force required for different plows, the accuracy of which none could dispute.

Fig. 101.



Self-recording Dynamometer.

DYNAMOMETER FOR ROTARY MOTION.

All these dynamometers apply only to simple, onward draught, as in plowing, drawing wagons, harrowing, &c. There is another, represented in *Fig.* 102, of very ingenious but complex construction, which shows the force required in working any rotary machine, such as thrashers, straw-cutters, and mills, and showing, at the same time, the velocity, and recording the number of revolutions made.

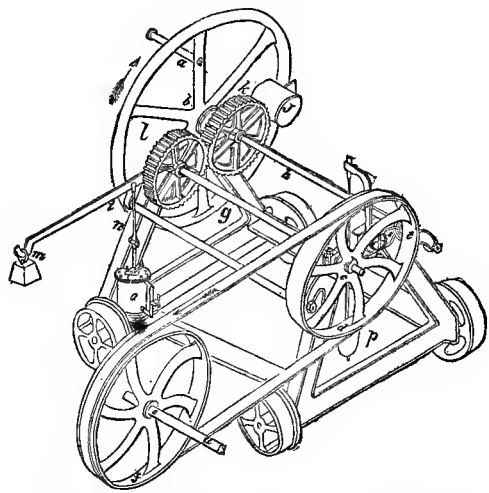
The whole machine is supported by a cast-iron framework, on four small wheels with flanges, like the wheels of rail-cars, that it may be conveniently run up on a temporary rail-way to the thrashing or other machine to be tried.

The band-wheel, *f*, on the shaft, *e*, is connected with the machine under trial, and the force is supposed, in this instance, to be applied by hand to the handle, *a*, on the fly-wheel.

When the fly-wheel is turned in the direction shown

by the arrow, it causes the two cog-wheels to revolve,

Fig. 102.



Dynamometer for measuring the force and velocity of thrashing-machines.

and moves the band in the direction shown by the other arrow. Now, whatever force is required to turn the wheel, *f*, connected with the machine under trial, must be overcome by a corresponding force applied to the handle, *a*, because the wheel-work is so adjusted that this handle moves with the same velocity as the band on the band-wheels.

The wheel, *f*, being connected by the band to the wheel, *d*, which is on the same axis or shaft as the cog-wheel, *l*, the resistance of the machine under trial tends to keep the cog-wheel, *l*, from turning, until enough force is applied to the handle, *a*, to set the cog-wheel, *k*, in motion. Now the greater the resistance, the greater will be the power needed at the handle. This

power, therefore, is measured accurately in the following manner:

The axle, *g*, of the cog-wheel, *l*, rests at its further end in an oblong hole or mortise, that allows it liberty to play, or rattle up and down within narrow limits. This same axle, *g*, passes through a hole in the lever, *i*, so that when it rattles up and down, it carries this lever up and down with it. The other part of the lever turns on the shaft, *h*, of the other cog-wheel.

Now when the man at the fly-wheel applies his force to the handle, *a*, the resistance of the machine under trial causes the cog-wheel, *l*, to refuse to turn; consequently, his force, instead of turning it, lifts it up in the mortise, and raises the lever with it. As he increases his force against the handle, let weights be hung on the lever, until, at the very moment that the wheel begins to *revolve*, the weights shall be just heavy enough to keep the lever down in the mortise. *This weight, therefore, will measure the exact force needed to turn the machine:* the greater the resistance of the machine, the greater must be the weight.

There is another weight, *J*, used to balance the lever and cog-wheel, *l*, while the machine is at rest, or before the force is applied to it, so that the weight at *m* shall represent the force truly. The weight, *m*, is, of course, to be multiplied by the power it exerts on the lever, *i*, which should be graduated like the bar of a steelyard.

There are a few other parts of this dynamometer not yet described. One is the cylinder, *o*, filled with oil, in which a perforated piston works, preventing the rapid vibration of the lever, *i*, as the force varies, pre-

cisely similar to the cylinder of oil described in *Fig.* 99. Another part is the pendulum, *p*, with the wheel, *r*, which measures the time.

The use of this instrument has been already attended with some important results in detecting the great amount of friction existing in some thrashing-machines of high reputation, which has been found to amount, in certain cases, to more than one half of the whole power applied. It is only by detecting so great a waste that we are enabled to take measures for its prevention.

CHAPTER VII.

CONSTRUCTION AND USE OF FARM IMPLEMENTS AND MACHINES.

SECTION I.

THE application of mechanical principles in the structure of the simpler parts of implements and machines has been treated of in a former part of this work. It remains to examine more particularly those machines chiefly important to the farmer, and to show the application of these principles in their use and operation.

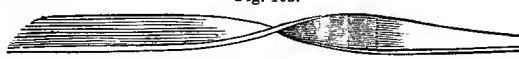
PLOWS AND PLOWING.

One great difference between good and bad plows is in the form of the mould-board. To understand the best form, it must be observed that the slice is first cut by the forward edge, and then one side is gradually raised until it is turned completely over, or bottom side up. To do this, the mould-board must combine the two properties of the wedge and the screw.

The position of the furrow-slice, from the time it is first cut till completely inverted, may be represented by placing a leather strap flat upon a table, and then, while holding one end, turning over the other, so as to bring that also flat upon the table, as in *Fig.* 103. Now the mould-board should have just such a shape as will fit the furrow-slice while in the act of turning

over, else it will wear unequally, become clogged with soil where the earth rubs slightly, and require greater strength in the team. By examining, it will be found that, although the strap (*Fig.* 103) twists like a screw,

Fig. 103.



yet all parts will be straight if measured across at right angles, as shown by the dotted lines. Therefore, by applying this principle, the farmer can judge of one important quality in selecting a plow. If, for example, he finds that a straight-edged stick will be flat upon the face at right angles to the line of motion, as shown by the dotted lines in *Fig.* 104, the mould-board will be so far right; but if the straight edge must be placed in other positions, as in *Fig.* 105, it is defective in form. A mould-board may be much modified, with this principle preserved in every instance; that is, it may be short, so as to raise the earth abruptly, or it may be long, so as to raise it gradually; it may be adapted to a deep furrow, lifting the furrow-slice to a considerable height, or to a shallow one, throwing it quickly over. These modifications are required for different soils and for different purposes. When, for example, it is desired to break up the slice and pulverize a heavy soil, the twist must be short and abrupt; when a sod in light soil is to be inverted smoothly, the mould-board must be longer, and the twist more gradual. In

Fig. 104.

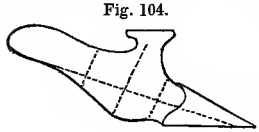
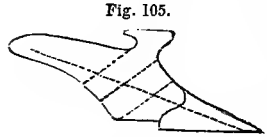


Fig. 105.



all mould-boards, care must be taken that the soil is not lifted so abruptly as to throw it forward, instead of simply turning it over.

Another defect in some plows is too blunt or thick a wedge formed by the share and mould-board. By the plow represented in *Fig.* 106, the earth must be thrown from the land-side into the furrow with a velocity about equal to the motion of the team; but by the one shown by *Fig.* 107, the team moves twice as fast as the earth is thrown by this longer wedge. Consequently, according to the rule of virtual velocities (already explained), as applied to the wedge, there is a great gain in power. Care must be taken, however, not to make this wedge too long, else the friction of a greater length of sod may overbalance the advantage.

Fig. 106.

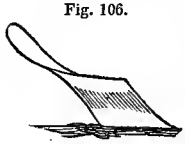
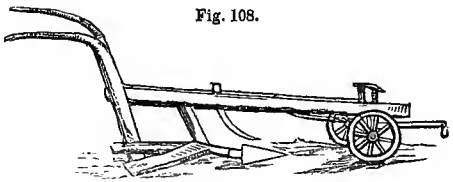


Fig. 107.

An attention to such principles as these has resulted in an extraordinary improvement within the past thirty years. Plows are made with one third the former cost, that will do more than twice as much work with the same strength of team, and do it so much better, that larger crops may be reaped from the same land. These advantages are so great, that on all the arable land of the Union there must be a yearly saving of ten millions of dollars in the work of teams, one million in the price of plows, and millions of bushels in the aggregate increase of crops by good tillage. In the two annexed figures we have a representation of an old and an improved plow.

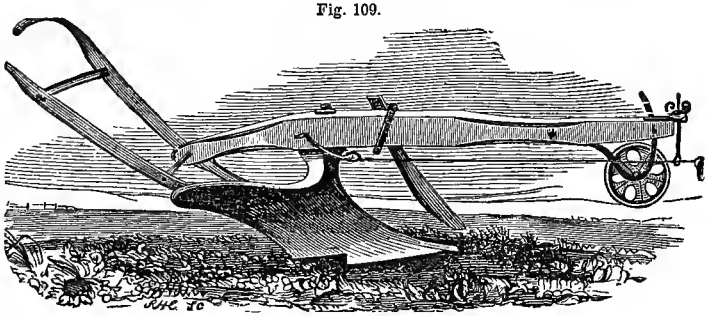
Fig. 108 is such a plow as is now used in some

Fig. 108.



parts of Germany. *Fig.* 109 is one of the best im-

Fig. 109.



proved cast plows. Nearly as great a difference exists between the plows used here fifty years ago and at the present time. Some portion of this great improvement may have been effected by persons not familiar with science; but if such persons were enabled to achieve so much, with the few truths which they had themselves laboriously discovered, how much more they might have accomplished if they had enjoyed the advantages of all that strong-minded men have discovered during the course of ages, and which is collected together in the form of modern science. How much more, too, would be saved in time and tedious experiments, by applying the principles of science already

discovered, than by ascertaining what we wish to know only by long-repeated trials.

TRENCH AND SUBSOIL PLOWING.

When the common two-horse plow alone is used by farmers, it pulverizes the soil only a few inches in depth, and its own weight, and the tread of the horses on the bottom of the furrow, gradually form a hard crust at that depth, through which the roots of plants and the moisture of rains do not easily penetrate. Hence the roots have only a few inches of good soil on the surface of the earth for their support and nourishment; and when heavy rains fall, the shallow bed of mellow earth is soaked and injured by surplus water. Again, in time of drought, this shallow bed of moisture is soon evaporated, and the plants suffer in consequence.

But, on the other hand, when the soil is made deep, it absorbs, like a sponge, all the rains that fall, and gradually gives off the moisture as it is wanted during hot and dry seasons. For this reason, deep soils are not so easily injured by excessive wetness, or by extreme drought, as shallow ones. In addition to this advantage, they allow a deeper range for the roots in search of nourishment.

Soils are deepened by *trench-plowing* and by *subsoiling*. By trench-plowing, the common plow with a mould-board is made to enter the earth to an unusual depth, and to throw up a portion of the subsoil, covering with it the top-soil which is thrown under. A subsoil plow, on the contrary, only *loosens* the subsoil, but does not lift it to the surface.

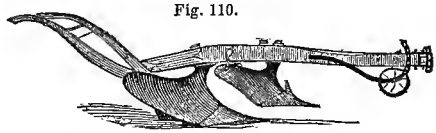
When a mixture of the subsoil with the surface tends to render the whole richer, trench-plowing is best; but when the subsoil is of a more sterile character, it should be only loosened with the subsoil plow, and more cautiously intermixed with the richer portion above.

It often happens that the subsoil plow is very useful in loosening the soil for the purpose of allowing the trench-plow to run more freely through it.

THE DOUBLE MOULD-BOARD TRENCH-PLOW.

This plow, sometimes called the *Michigan Double Plow*, is represented in *Fig.* 110. It has two mould-

Fig. 110.

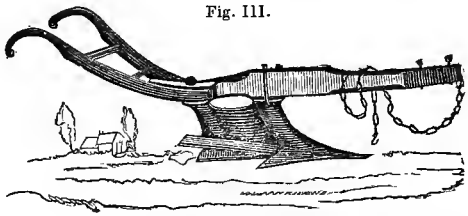


boards on one beam. The forward or small one pares off the surface or sod, and throws it into the previous furrow, usually to a depth of three to five inches. The larger one follows closely, lifting the under-soil upon the top, and in sward land completely burying the sod with the mellow earth from below. This is the best implement for trench-plowing yet introduced into practice, and with double the ordinary amount of team, will cut to a depth of nine to twelve inches.

THE SUBSOIL PLOW,

represented in *Fig.* 111, consists of a narrow, horizon-

Fig. 111.



Subsoil plow.

tal, wedge-like share for loosening the earth, and connected with the beam by a strong plate of metal running edgewise, so as to cause little resistance through the soil. This plow follows in the furrow after a common plow, loosening but not lifting out the earth. The operation is shown in *Fig.* 112. The benefit of sub-

Fig. 112.

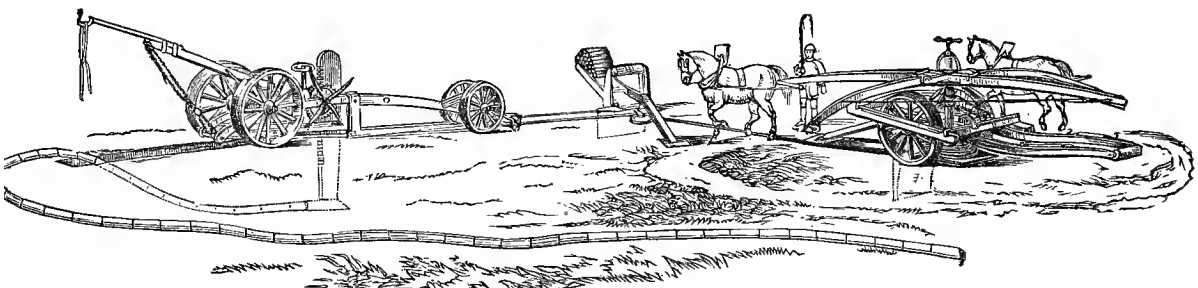
Subsoil plowing in the furrow of a common plow.

soiling will last three or four years; but it is of great importance that land be well underdrained, for if the earth becomes heavily soaked with water, it settles down into one compact mass, and the advantages of the operation are lost.

FOWLER'S DRAINING PLOW.

The mole-plow, for forming a small hollow passage beneath the soil, by means of a sharp iron plug forced through it at the lower end of a thin coulter, has been

Fig. 113.



Fowler's Drain-plow, making a tile-drain, without digging, by means of tile strung on a rope, and drawn under the surface after an iron plug.

already described. A great improvement has been made in this machine by the invention of the *Draining plow*, *Fig.* 113, opposite, which not only forms a hole through the subsoil, but fits into it at the same operation earthen pipe or tubular tile, forming at once a perfect and durable under-drain. The pieces of tile or pipe, which are about a foot long, are strung on a rope, as shown in the foreground of the engraving. This rope is attached to the back end of the iron plug, and is drawn forward through the earth as the plug advances, thus fitting the hole with tile as fast as it is formed. The only trace left on the surface of the earth is a narrow slit made by the coulter, an invisible drain being formed beneath it.

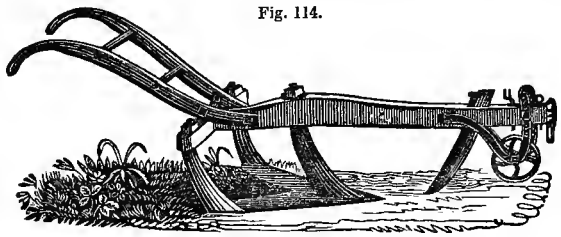
The frame-work to which the coulter and plug are attached is drawn forward by an iron rope (made of twisted wire) wound upon a windlass or capstan worked by horses. Drains forty rods long are completed at one operation. A short piece of ditch is first dug for the admission of the plug, and strings of pipe, each fifty feet long, are successively added, and when done the whole of the rope is withdrawn.

When the surface of the ground is uneven, an ingenious contrivance preserves a straight and uniform slope to the drain. The coulter is worked up or down by the man who stands on the frame, by means of a wheel and screw, his eye being guided by a try-sight on the frame, and a cross-staff at the end of the field, set so as to give a proper slope. This machine, when tried in England, has been found to accomplish the work of draining with less than one half the ordinary expense.

THE PARING PLOW

consists merely of a flat blade, which runs beneath the surface, shaving off the roots, but not moving the soil (*Fig.* 114). It is used in cutting turf for burning,

Fig. 114.



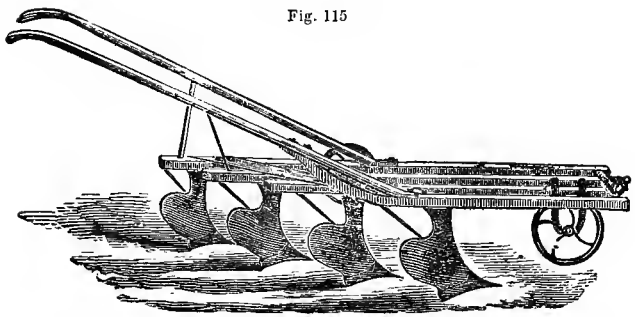
Paring plow.

and for destroying thistles and other deep-rooted weeds. When made light for a single horse, it is sometimes used advantageously for cutting the grass and weeds between rows of corn. A two-horse paring plow has been lately constructed, in which the depth of cutting is accurately regulated by wheels placed on an axle like those of a cart. The cast-iron blade, which cuts about three feet wide, is raised or depressed by means of screws passing through the axle. Its chief utility is in destroying grass and weeds before the sowing of broadcast crops.

THE GANG PLOW

consists of three or four small mould-boards placed side by side (*Fig.* 115), and is used for shallow plowing, or burying manure or seed on inverted sod, without disturbing the turf beneath. In those of the best construction, the depth is regulated by wheels, and the breadth of the furrows by turning the cross-beam more

Fig. 115



Gang plow.

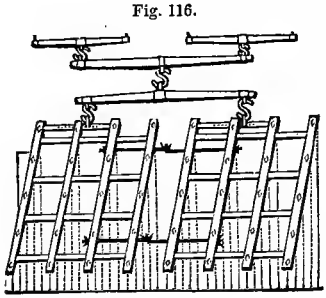
or less obliquely, by means of a fixed contrivance for this purpose.

SECTION II.

PULVERIZERS.

THE fine pulverization of the soil, for the ready extension of the fine roots of plants, and for the thorough intermixture of manure, is of great importance to the farmer. It is but partially accomplished by the plow, which crumbles the soil only so far as may be done by the act of turning it over. Hence additional implements are needed for this purpose, among which are the *harrow*, the *cultivator*, and the *clod-crusher*.

Fig. 116.



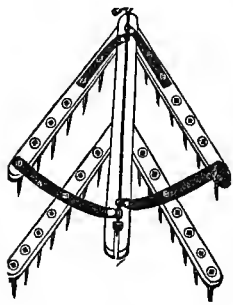
Scotch or square harrow.

THE HARROW

The common form of the harrow is represented by *Fig.* 116, which consists of two parts hung

together by hinges, so as to bend and fit an uneven surface of land, and to be folded for carrying in a cart or wagon. The dottted lines show the track of each tooth. The *Geddes Harrow*, represented in *Fig.* 117, is superior to the square harrow on account of its drawing more steadily from a centre, and its wedge-form frame passing more freely past any unusual obstruction. To prevent the central part from being lifted by the draught, the draught-chain is fastened to the side-beams, as in *Fig.* 118.

Fig. 117.



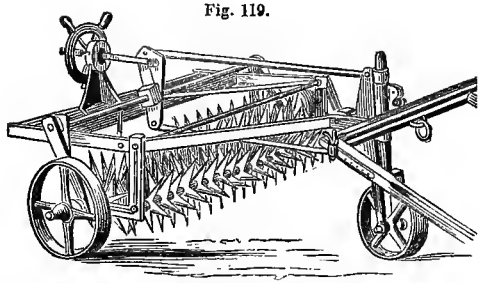
Geddes Harrow.

Fig. 118.

The teeth of harrows are often made too large and too few in number. Small and very numerous teeth pulverize the soil more finely and rapidly. They should be so placed that the corners, like wedges, and not the sides, may cut the soil in their onward progress; and if the forward half of the teeth were made sharp and flat, similar to the coulter of a plow, they would not only run more easily, but cut and pulverize clods more efficiently. This form of the teeth would admit of the use of cast-iron, which would be cheap and durable.

The *Norwegian Harrow*, *Fig.* 119, is a new machine for pulverizing the soil, which performs the work in a very perfect manner, by turning up instead of packing down the earth. Two rows of star-shaped tines play into each other, and produce a complete self-

Fig. 119.



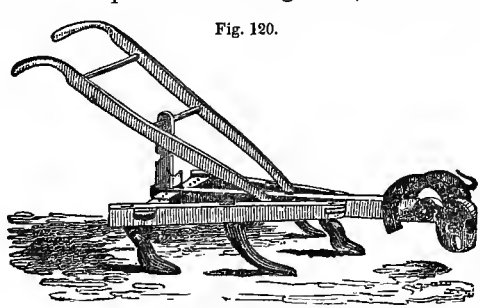
Norwegian Harrow, kept from clogging by two cylinders of teeth ploying into each other.

cleaning action, preventing clogging even in quite adhesive soils.

CULTIVATORS.

The cultivator is used for loosening and pulverizing the soil, and for cutting and destroying weeds. The usual form is represented in *Fig.* 120, where the wheel

Fig. 120.



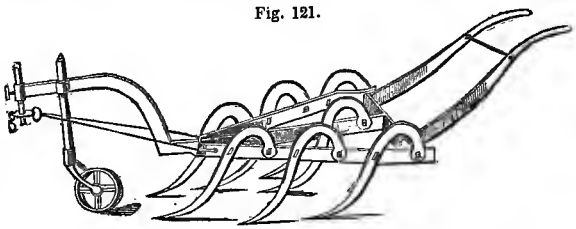
Common Cultivator.

in front regulates the depth of the teeth. The width is altered by expanding or contracting the two outer beams.

Various sorts of teeth are used, according to the nature of the work, and they are made of steel or cast-

iron. The cast-iron teeth, represented in *Fig.* 120, are well adapted for cultivating the rows of Indian corn and other hoed crops, where the soil is already moderately mellow. For harder soils, the teeth should be in the form of claws, as shown in *Fig.* 121, their

Fig. 121.

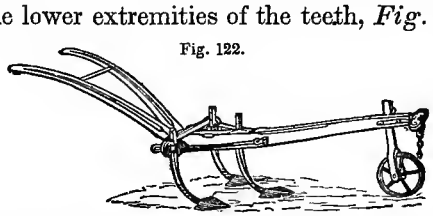


Claw-toothed cultivator for hard ground.

sharp, wedge-form points penetrating and loosening the earth with comparative ease. A very efficient cultivator is made by using both kinds of teeth in the same implement, placing the claws forward for breaking the hard earth, and the broader teeth behind for stirring it.

Steel plates, with sharp or "duck-feet" edges screwed at the lower extremities of the teeth, *Fig.* 122, are

Fig. 122.



useful for paring, or cutting the roots of weeds; and formed like the mould-board of a plow, they are sometimes used for throwing the mellow earth toward the row, or, when reversed, from it.

In all cases, the teeth should be so long and the frame-work high enough above ground to allow room

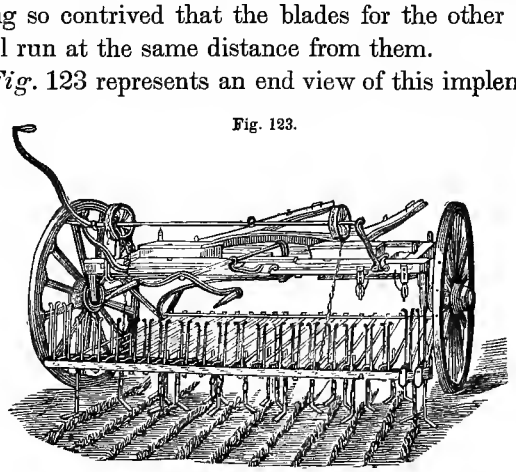
for the weeds to gather and fall off, even when the teeth are deepest in and the land the foulest.

Two-horse cultivators are very useful in pulverizing the surface of inverted sod, and fitting it for the reception of seed. They run on wheels, and an apparatus is attached for lowering or raising the frame-work and regulating the depth of the teeth.

Garrett's Horse-hoe, an English invention, is a modification of the cultivator, and is used for cultivating carrots and other root-crops in drills, cleaning eight or ten rows at once. It is furnished with sharp horizontal blades, which run beneath the surface, and shave off and destroy all the weeds within an inch of the rows of young plants. These rows, having been planted by means of a drilling-machine, are straight and perfectly parallel, and the operator has only to watch *one* row and guide the blades for that row, the apparatus being so contrived that the blades for the other rows shall run at the same distance from them.

Fig. 123 represents an end view of this implement.

Fig. 123.



Garrett's Horse-hoe—End view.

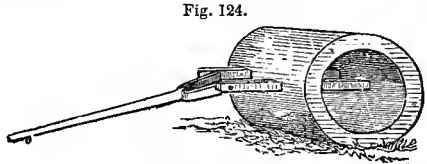
It exhibits the apparatus by which the length of the axle is altered to suit all kinds of planting; by which each hoe is kept independent of the others, so as to suit the inequalities of the ground, and by which they can be set any width, from seven inches to thirty. It shows the oblique angle at which they run—this obliquity being easily altered to any desired degree: this is effected by a movement of the upper handle represented in the figure. By the lower handle the whole is accurately guided. It is said that two men, one to lead the horse, and the other to guide the implement, will dress ten acres of root-crops in a single day, and that it has proved eminently a labor-saving machine.

CLOD-CRUSHERS.

In clayey soils, clods are often formed in abundance during the process of cultivation. These become very hard in dry weather, and prevent the proper extension of the fine roots of plants in search of nourishment, and also the intermixture of manure with the soil, without which it has been found that two thirds or even three fourths of the value of manure is lost to growing crops.

Different modes of pulverizing the clods have been adopted. The simplest is the "*drag-roller*," represented in *Fig.* 124. It is made of a log or portion of

Fig. 124.

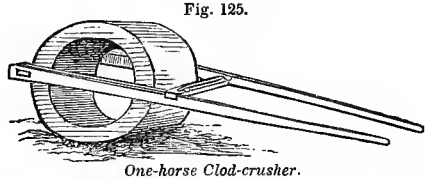


Clod-crusher.

a hollow tree, into which a common two-horse wagon

tongue has been fitted, by which it is dragged over the ground without rolling, grinding to powder, in its progress, every clod over which it passes. The greater the diameter of the log, the less will be the liability of its clogging by gathering the clods before it. It may also be made of a half log with the round side downward. *Fig.* 125 represents a similar implement

Fig. 125.



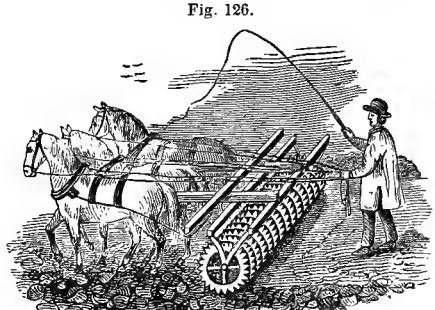
One-horse Clod-crusher.

for one horse, and is used for working between the rows of corn in cloddy ground.

The use of these simple implements, by reducing rough fields to a condition as mellow as ashes, has in some instances been the means of doubling the crop. It is necessary that the soil be dry when they are used, to prevent its packing together.

Crosskill's Clod-crusher is a more powerful and

Fig. 126.



Crosskill's Clod-crusher.

more costly implement (*Fig.* 126). It consists of about two dozen circular cast-iron disks, placed loosely upon an axle, so as to revolve separately. Their outer circumference is formed into teeth, which crush and grind up the clods as they roll over the surface of the field. Every alternate disk has a larger hole for the axle, which causes it to rise and fall while turning over, and thus prevent the disks from clogging. It can be used only when the ground is dry.

SECTION III.

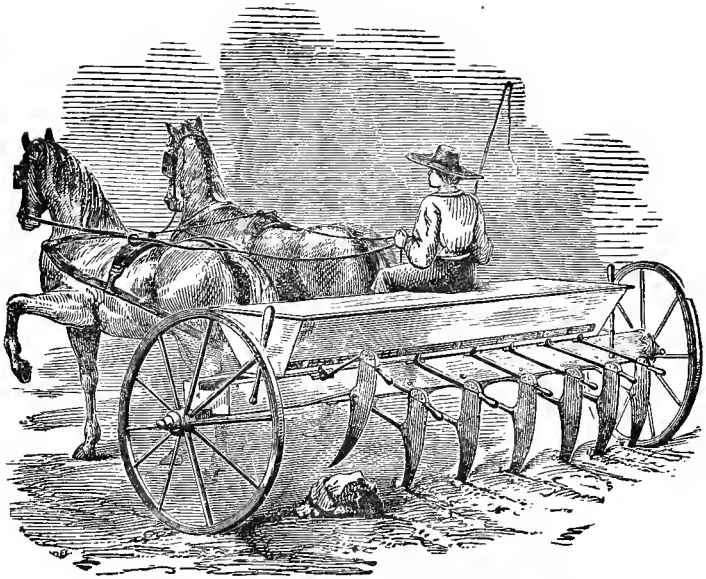
SOWING-MACHINES.

Sowing-machines, for wheat and other grains, possess great advantages over hand-sowing. All the seed being deposited by them at nearly a uniform depth, and completely covered with earth, it vegetates and grows evenly, and the plants are uniformly strong and vigorous. A less quantity of seed is required, and the crop is heavier.

Small seeds, such as carrots and turnips, can be sown evenly and rapidly only by means of drills adapted to these seeds, and hence drilling-machines are indispensable in the cultivation of such root-crops.

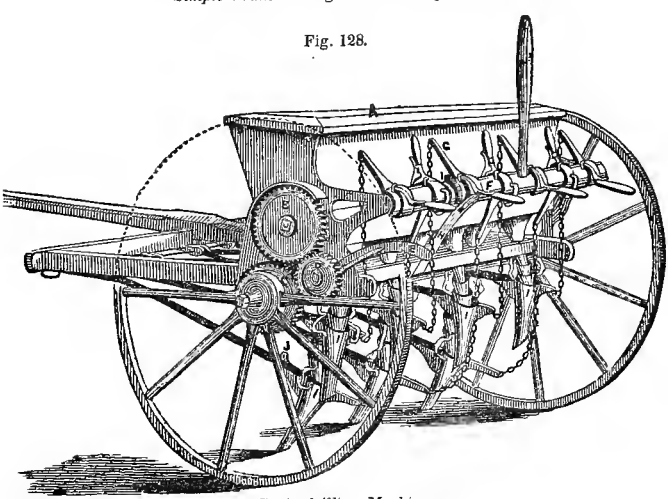
A great number of different drills have been made for sowing grain, the general principles of which can be only noticed in this treatise. The seed is delivered by means of a revolving cylinder, in the surface of which small regular cavities have been made, which constantly carry off and drop measured portions of the grain. The motion of this cylinder is increased or lessened by means of wheel-work, according to the quan-

Fig. 127.



Simple Grain-drilling Machine in operation.

Fig. 128.



Grain-drilling Machine.

tity of seed to be sown. As soon as the seed drops from the revolving cylinder, it falls down either through a hollow coulter, or through a tube which opens just behind a coulter, into the bottom of the furrow, and is immediately buried by the earth falling back upon it after the coulter has passed.

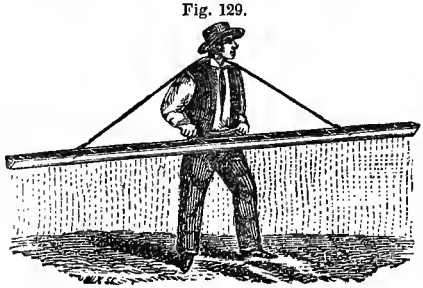
Drills for sowing small seeds are usually furnished with a spindle having circular brushes, which press the bottom of the hopper, and force the seed through small holes made for its escape.

For planting corn, beans, and other crops cultivated in drills and hills, the machines are so regulated as to drop either in hills or in uniform rows, and they do the work more evenly than when performed by hand.

The coulters or tubes for depositing the seed should, in all machines of this kind, be made sharp and not rounded on the forward part, that the draught may be easier.

A simple grain-drill is represented in operation by *Fig.* 127, and one of more finished construction by *Fig.* 128, showing the cog-wheel gearing for regulating the quantity of seed, and the chains for lifting up the discharging tubes from the ground when not in use.

Fig. 129.



A very simple machine for sowing grass, as well as other small seed, by hand, is shown in the annexed figure. It consists of a light trough, contain-

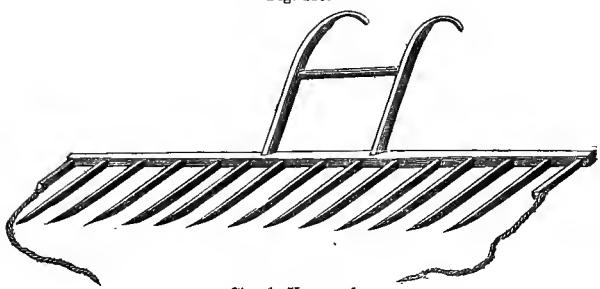
ing the seed, which is distributed through holes in the zinc bottom by the vibrations of a notched rod, and any desired quantity of seed accurately regulated.

HORSE-RAKES.

In all labor-saving contrivances, the greatest advantage is gained where the work originally performed by the hand is light, or where much exertion of strength is not required. An example of this kind occurs in the use of hand-drills for sowing small seeds, such as turnips and carrots. These, when planted by the unassisted hand, require but little power, but the operation is very slow. A hand-drill enables the laborer to apply his whole strength profitably, with an increase in effect of at least forty or fifty times. A similar advantage is gained by the use of the horse-rake, where the full strength of a horse is made to accomplish the moderate labor of the hand-rake, and to perform an amount equal to at least ten men. With the simplest form of the horse-rake, sixteen acres of heavy hay have been collected by one horse in a day, and with the revolving-rake, twenty to twenty-five acres.

The simplest form of the horse-rake is represented in *Fig.* 130. It is made of a piece of strong scantling three inches square, tapering slightly toward the ends, for the purpose of combining strength with lightness, and in which are set horizontally about fifteen teeth, twenty-two inches long, and an inch by an inch and three fourths at the place of insertion, tapering on the under side, with a slight upward turn at the points, to prevent their running into the ground. The two outer teeth should be cut off to about one third their first

Fig. 130.



Simple Horse-rake.

length, and draught-ropes attached. If they are too short, the teeth will be hard to guide; if too long, the rake is unloaded with difficulty. Handles serve to guide the teeth, to lift the rake from the ground in avoiding obstructions, and to empty the accumulated hay.

In using this rake, the teeth, instead of moving on their points as in the common hand-rake, run flat upon the ground, passing under and collecting the hay. When full, the horse is stopped, the handles thrown forward, the rake emptied and lifted over the winrow thus formed. The winrows are made at right angles to the path of the rake, as each load is deposited opposite the last heap formed in previously crossing the meadow. A few hours' practice enables any one to use this rake without difficulty; the only skill required is to keep the teeth under the hay and above the ground. When small obstructions occur, the handles are depressed, and the points of the teeth rise and pass freely. Over large obstructions, the rake must be lifted. By shortening the teeth, it may be used on the roughest ground.

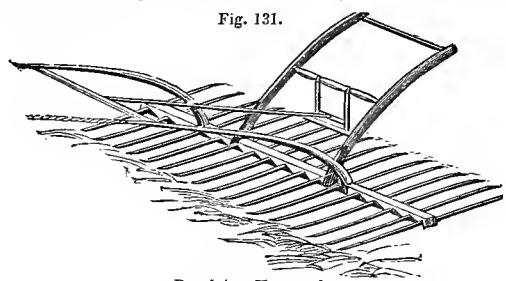
In addition to raking, this implement may be em-

ployed for sweeping the hay from the winrow and drawing it to the stack. It is also useful for cleaning up the scattered hay from the meadow at the close of the work, for raking grain-stubble, and for pulling and gathering peas.

Its chief advantages over other horse-rakes are its simplicity, cheapness, and little liability to get out of order—adapting it to small farms—and its superior fitness for uneven surfaces. If made of the toughest wood, and with the proper taper in the main parts for lightness and strength, according to the principles already pointed out in a previous chapter, it is easily lifted, and its use not attended with severe labor.

The *Revolving Horse-rake*, *Fig.* 131, is similar in

Fig. 131.



Revolving Horse-rake.

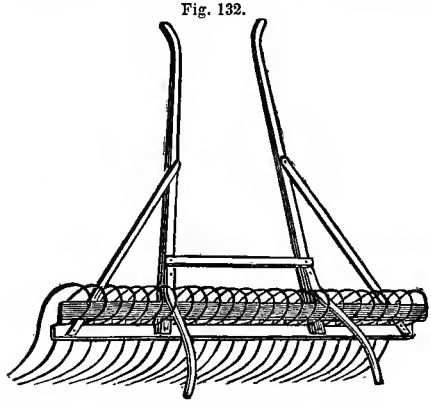
its mode of operation, possessing, however, the great advantage of unloading without lifting the rake or stopping the horse. It has a double row of teeth, pointing each way, which are brought alternately into use as the rake makes a semi-revolution at each forming winrow in its onward progress. They are kept flat upon the ground by the pressure of the square frame on their points beneath the handles; but as soon as a load of hay has collected, the handles are slightly raised, throw-

ing this frame backward off the points, and raising them enough for the forward row to catch the earth. The continued motion of the horse causes the teeth to rise and revolve, throwing the backward teeth foremost over the winrow. In this way each set of teeth are alternately brought into operation.

The cost of the revolving rake, well made, is about four times that of the simple horse-rake, but on large meadows it possesses the superior advantages of expedition and ease in working.

The *Spring-tooth Horse-rake*, *Fig.* 132, has been

Fig. 132.



Spring-tooth Horse-rake.

much used, and has proved a valuable implement. The teeth are made of stiff, elastic wire, on the *points* of which the rake runs, and not on the flat sides, as in the two already described. They bend in passing an obstruction, and spring back again to their place. This rake is unloaded by simply lifting the handles, which is easily done, the rake being light, and about one half the weight being sustained by the horse. It is pecu-

liarly adapted to raking stubble, its upright teeth preventing the collection of portions of the soil with the straw.

All horse-rakes used on meadows are not only useful by the immediate saving of labor, but sometimes still more so by the expedition with which a crop of well-dried hay may be rescued from an approaching storm.

MOWING AND REAPING MACHINES.

The cutting part of all the best mowers and reapers made at the present day consists of a serrated blade, as shown at *a* (*Fig.* 133), which passes through narrow slits in each of the fingers shown in *b*, forming, when thus united, the cutting apparatus, as exhibited in the annexed figure of *Ketchum's Mowing-machine* (*Fig.* 134). When the machine is used, the motion of the

Fig. 133.

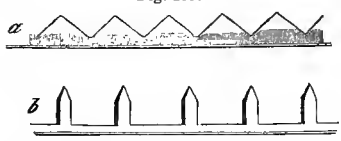
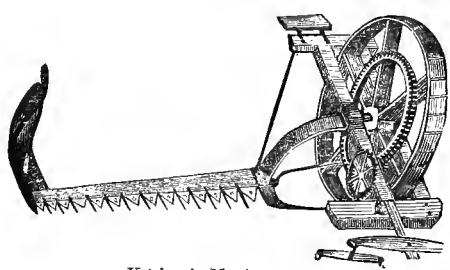


Fig. 134.

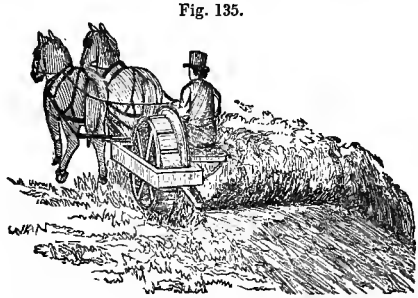


Ketchum's Mowing-machine.

wheel on which the machine runs is multiplied by means of the cog-wheels, imparting quick vibrations

endwise to this blade, shearing off the grass smoothly as it advances through the meadow, like a large number of scissors in exceedingly rapid motion. *Fig.* 135

Fig. 135.

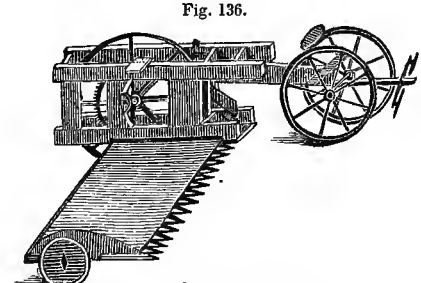


Back view of Ketchum's Mower in operation.

represents Ketchum's mower in operation as seen from behind, cutting an even swath five feet wide as fast as the horses advance.

In the mowing-machine the cutting apparatus is narrow, causing the newly-cut grass to fall evenly behind it, covering the whole surface of the ground. The reaping-machine is similar in construction, with the addition of a platform for holding the grain as it falls, as shown in the figure of *Hussey's Reaper* (*Fig.* 136).

Fig. 136.



Hussey's Reaping-machine.

As the straw collects on this platform, it is raked off in successive bunches for binding by a man who rides on the machine for this purpose.

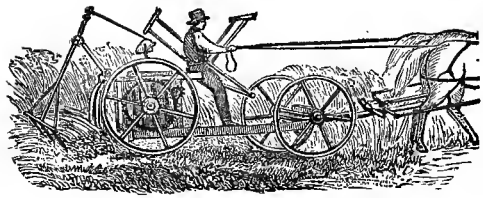
Most reaping-machines are provided with a revolving reel, which strikes backward against the standing grain, holds it there while the blade is cutting, and throws it backward on the platform. This reel is distinctly shown in the representation (*Fig.* 137) of *Manny's Mowing and Reaping Machine*, where the cutting blade is placed midway between the forward and back wheels.

Fig. 137

Manny's Mowing and Reaping Machine, showing the reel distinctly.

Mowing machines require but one man for their management, who merely drives the horses that draw it. Reapers, as usually made, require another man besides the driver, to rake off the bunches of cut grain, which is severe labor. Various *self-raking* contrivances have been tried to obviate this labor, one of the most ingenious and best of which is *Atkins' Self-raker*, represented by *Fig.* 138, and sometimes called the *Automaton Raker*. An ingenious piece of mechanism causes the rake to sweep the platform, and presses the fallen grain against another rake, when both of them, with the bundle of grain firmly inclosed, swing round behind, and then open wide, and drop it on the ground ready for binding. It may be so regulated as to drop

Fig. 138.



Atkins' Automaton Reaper in operation.

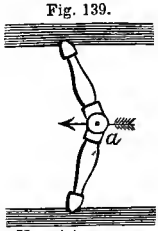
the bunches more frequently where the crop is heavy, or more remotely where it is light.

SECTION IV.

THE KNEE-JOINT POWER APPLIED TO MACHINES.

THE *knee-joint* or *toggle-joint* is usually regarded as a compound lever, and consists of two rods connected by a turning joint, as represented in *Fig.* 139. The outer end of one of the levers is fixed to a solid beam, and the other connected with a movable block. When the joint *a* is forced in the direction indicated by the arrow, it produces a powerful pressure upon the movable block, which increases as the lever approaches a straight line. This is easily understood by the rule of virtual velocities, for the force moves with a velocity many times greater than the power given to the block, and this relative difference increases as the joint is made straighter.

Fig. 139.

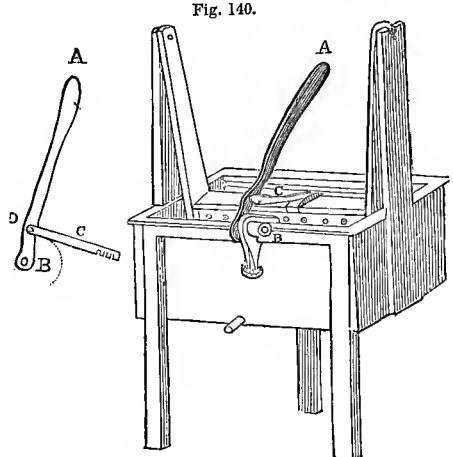


Knee-joint power.

This power is made use of in the lever printing-press, where the greatest force is given just as the pressure is completed. Another example occurs in the *Lever*

Washing-machine (*Fig.* 140), which is worked by the alternating motion of the handle, A, pressing a swinging-board, perforated with holes, with great force

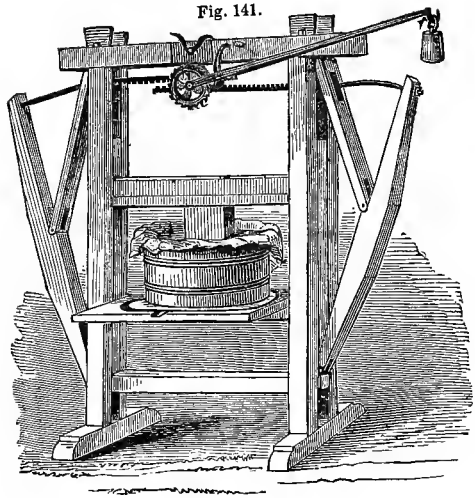
Fig. 140.



Lever Washing-machine.

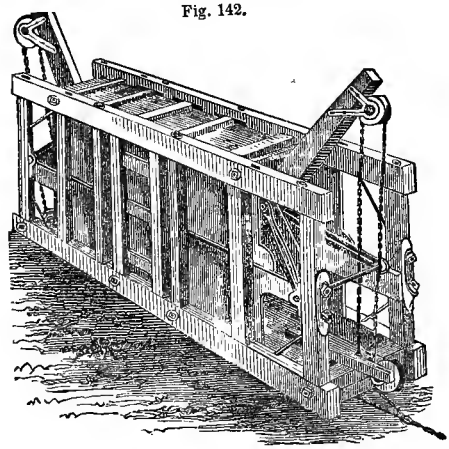
against the clothes next to one side of the water-box. Like the printing-press, this machine exerts the greatest power just as the motion of the lever is completed, and at the time it is most needed. The same principle is exhibited in *Kendall's Cheese-press* (*Fig.* 141), where the lever and the wheel-and-axle are combined with the two knee-joints, one on each side of the press, drawing down a cross-beam upon the cheese with a greatly multiplied power. *Emery's Hay-press*, for compressing hay into bales for distant conveyance, is another example (*Fig.* 142). The hay is thrown into a space in a strong box by opening the top doors, and when trodden down, the doors are closed and secured by buttoning down the cross-bars. Horse-

Fig. 141.



Kendall's Cheese-press.

Fig. 142.



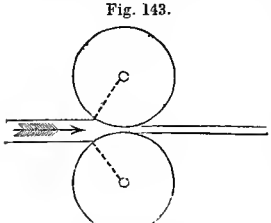
Emery's Hay-press.

power is then applied to chains, which draw down the

raised levers, operating on a knee-joint, and compressing the hay into a small and compact mass, the greatest force being given when most needed, at the termination of the pressure. Side-doors are then thrown open, and the hay secured by bands and taken out. Two hundred and fifty pounds of hay may be thus reduced to a space of sixteen cubic feet, or a little more than half a cubic yard, by a single horse; and several tons may be pressed in a day. Dederick's improvement in this press consists in placing the levers at one end only, compressing the hay into the other end, and thus simplifying the machine. Double levers, pressing equally against the upper and lower part of the slide or piston, keep it always upright and even, although the hay may be unequally compact. These double levers are connected and kept parallel by connecting hinged bars.

The power exerted by a *rolling-mill*, where bars of iron are flattened in their passage between two strong rollers, is precisely like that of the knee-joint. The only difference is, that the rollers, which may be considered as a constant succession of levers coming into play as they revolve, are both fixed, and consequently the bar has to yield between them (*Figure* 143). The greatest power is exerted just as the bar receives the last pressure from the rollers. The most powerful and rapidly-working straw-cutters are those which draw the straw or hay between two rollers, one of

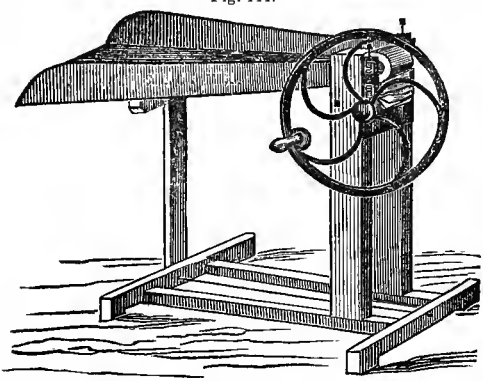
Fig. 143.



Principle of the knee-joint in the rolling-mill.

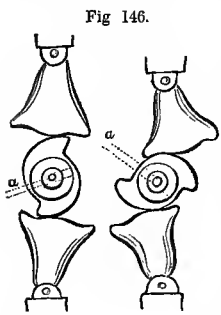
which is furnished with knives set around it parallel with its axis, and cutting on the other, which is covered with untanned ox-hide (*Fig.* 144). The only de-

Fig. 144.



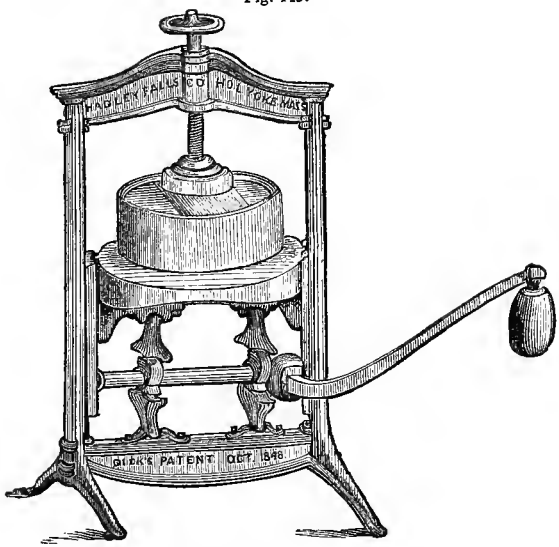
fect in this machine is its inability to cut shorter than one inch in length, which is not sufficient for corn-stalks and other coarse fodder.

Fig 146.



Dick's Cheese-press (*Fig.* 145, on the following page) operates on a similar principle. *Figure* 146 shows the structure of its working part, the dotted lines indicating the position of the lever, which is inserted into a roller or axle, and, by turning, drives the movable iron blocks asunder, and raises the cheese against the broad screw-head above, as shown in *Fig.* 145. In *Fig.* 146, the raised lever shows that the blocks are at first near together, but are crowded asunder as the lever is pressed downward. This cheese-press is made of cast-iron,

Fig. 145.



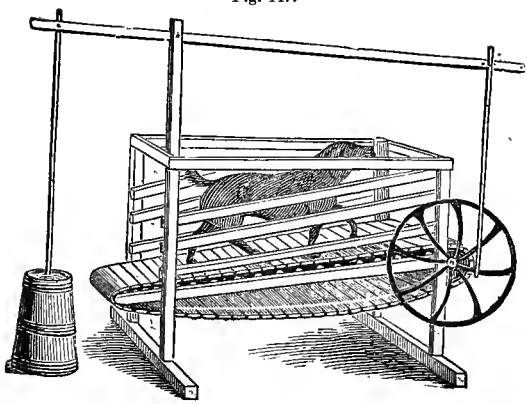
Dick's cast-iron Cheese-press.

and has great power; to try it, weights were increased upon the lever, until the iron frame broke with a force equal to sixteen tons.

ENDLESS-CHAIN POWERS.

A convenient and compact machine for applying animal power is by means of the endless chain, working in the position of an inclined plane, as represented in the annexed cut (*Fig.* 147), where the weight of a large dog is used for driving a churn-dasher. The platform on which the animal stands is formed of strips of light wood riveted to two India-rubber straps, and their constant downward motion turns the fly-wheel, to which a rod is attached for working the dasher.

Fig. 147.



Churn worked by dog-power.

The same principle has been lately adopted with great success in the application of horse-power to driving thrashing-machines, sawing wood, and to various other purposes. Instead of India-rubber straps, strong cast-iron chains are used, which are made to run smoothly and with very little friction over a succession of small iron wheels, which support the weight of the horses on the moving platform (*Fig.* 148, on the following page).

The power of these machines, and the amount of friction in running them, may be easily ascertained by the rule, already given in a former part of this work, for determining the power of the inclined plane; for the only difference between the endless-chain and a common inclined plane is, that in one the plane is fixed, and the body moves up its surface, and in the other the plane itself moves downward, and the weight or animal upon it remains stationary. The same prin-

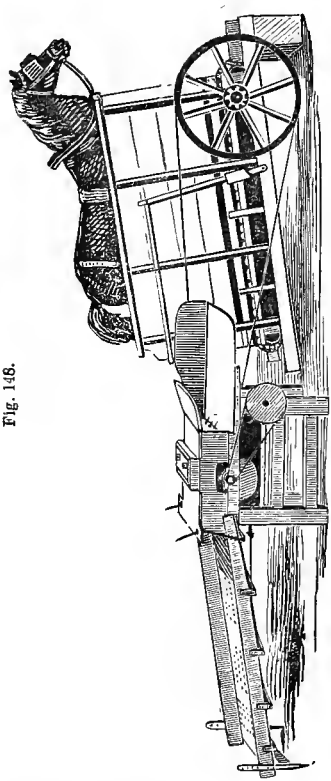


Fig. 146. *Endless-chain horse-power, driving a thrashing-machine.*

ciple applies in both cases.

First, to ascertain the friction, let the platform be placed on a level, with the horse upon it; then gradually raise the end until the weight of the horse will just give it motion. This will show the precise amount of the friction; for if the end be elevated one twentieth of its length, then the friction is one twentieth the weight of the horse and platform.

Secondly, to determine the power, when the end is still further raised, measure the difference between the height thus given and the length of the platform. If, for instance, the height of the inclination is one eighth of its length, and the horse is found to weigh eight hundred pounds, then the power is one hundred pounds, or one eighth the weight of the horse.

This rule will not, however, apply, when the *draught* of the horse is added to its weight; for it usually happens that the weight alone is not sufficient, without

placing the platform in too steep a position for a horse to work comfortably. He is therefore attached to a whipple-tree placed on the frame of the machine, so that in drawing he pushes the platform backward with his feet. In this case, the power can be only ascertained by the use of the dynamometer, already described.

SECTION V.

APPLICATION OF LABOR.

Most of the moving powers applied by the farmer to accomplish labor are the exertions of animal strength. A principal object of the preceding pages is to point out how this strength can be applied in the most economical manner, and to aid in the substitution of cheap horse-power for more costly human labor. It will doubtless contribute to the end to exhibit the relative efficiency of each, as well as the results of strength differently applied.

The amount of work which any machine is capable of performing is denoted by comparing this amount with the power of a single horse; hence the common expressions of twenty, or fifty, or a hundred horse-power engines. The strength of different horses varies greatly, but the expression, as commonly understood, indicates a force equivalent to raising or pressing with a force equal to 150 pounds 20 miles a day, at the rate of two and a half miles an hour. This is the same as 33,000 pounds raised one foot in one minute. The results of numerous experiments in different places give the actual power of the average of horses at somewhat

less than this; and there is no doubt that, for most of the farm-horses of this country, the result would be considerably less. The power of a strong English draught-horse has been ascertained to be about 143 pounds for 22 miles a day, at $2\frac{3}{4}$ miles an hour. Many American horses are scarcely more than half as strong. The strength of a man, working at the best advantage, is estimated at one fifth that of a horse. As the speed of a horse increases, his strength of draught diminishes very rapidly, till at last he can only move his own weight. This is owing to three reasons: first, the load moves over a greater space in a given time, and if, for instance, the speed be doubled, half the load only can be carried with the same quantity of power, according to the law of virtual velocities; secondly, the horse has to carry the full weight of his body, whatever his speed may be, and the force expended for this purpose alone must, therefore, be doubled as the speed is doubled; thirdly, a very quick and unaccustomed motion of the muscles is in itself more fatiguing than the ordinary or natural velocity.

The following table shows the amount of labor a horse of average strength is capable of performing in a day at different degrees of speed, on canals, rail-roads, and on turnpikes. The force of draught is estimated at about 83 pounds. This is considerably less than the horse-power used in estimating the force of machinery, but it is as much as an ordinary horse can exert without being improperly fatigued with continued service:

Velocity per hour.	*Duration of the day's work.*	*Work accomplished for one day, in tons, drawn one mile.*		
Miles.	Hours.	On a canal.	On a rail-road.	On a turnpike.
$2\frac{1}{2}$	$11\frac{1}{2}$	520	115	14
3	8	243	92	12
$3\frac{1}{2}$	$5\frac{9}{10}$	153	82	10
4	$4\frac{1}{2}$	102	72	9
5	$2\frac{9}{10}$	52	57	7.2
6	2	30	48	6
7	$1\frac{1}{2}$	19	41	5.1
8	$1\frac{1}{8}$	12.8	36	4.5
9	$\frac{9}{10}$	9	32	4
10	$\frac{3}{4}$	6.6	28.8	3.6

From the preceding table it will be seen that a horse, at a moderate walk, will do more than four times as much work on a canal as on a rail-road; but the resistance of the water increases as the square of the velocity, and therefore when the speed reaches five miles an hour, the rail-road has the advantage of the canal. On the rail-road and turnpike the resistance is about the same, whether the speed be great or little, the chief loss with fast driving resulting from the increased difficulty with which the horse carries forward his own body, which weighs from 800 to 1200 pounds. The table also shows that when it becomes necessary to drive rapidly with a load, it should be continued but for a very short space of time; for a horse becomes as much fatigued in an hour, when drawing hard at ten miles an hour, as in twelve hours at two and a half miles an hour; because, when a boat is driven through the water, to double its velocity not only requires that twice the amount of water should be moved or displaced in a given time, but it must be moved with twice the velocity, thus requiring a four-fold force.

The muscular formation of a horse is such that he

will exert a considerably greater force when working horizontally than up a steep inclined plane. On a level, a horse is as strong as five men, but up a steep hill he is less strong than three; for three men, carrying each 100 pounds, will ascend faster than a horse with 300 pounds. Hence the obvious waste of power in placing horses on steeply-inclined tread-wheels or aprons. The better mode is to allow them to exert their force more nearly horizontally, by being attached to a fixed portion of the machine. For the same reason, the common opinion is erroneous that a horse can draw with less fatigue on an undulating than on a level road, by the alternations of ascent and descent calling different muscles into play, and relieving each in turn; for the same muscles are alike exerted on a level and on an ascent, only in the latter case the fatigue is much greater than the counterbalancing relief. Any person may convince himself of the truth on this subject by first using a loaded wheel-barrow or hand-cart for one day on a level, and for the next up and down a hill; bearing in mind, at the same time, that the human body is better fitted for climbing and descending than that of a horse.

A *draught-horse* can draw 1600 pounds 23 miles in a day on a good common road, the weight of the carriage included. On the best plank-road he will draw more than twice as much.

A *man* of ordinary strength exerts a force of 30 pounds for 10 hours a day, with a velocity of $2\frac{1}{2}$ feet per second. He travels, without a load, on level ground, during $8\frac{1}{2}$ hours a day, at the rate of 3.7 miles an hour, or $31\frac{1}{4}$ miles a day. He can carry 111 pounds 11

miles a day. He can carry in a wheel-barrow 150 pounds 10 miles a day.

Well-constructed machines for saving human labor by means of horse-labor, when encumbered with little friction, will be found to do about *five times* as much work for each horse as where the same work is performed by an equal number of men. For example: an active man will saw twice each stick of a cord of wood in a day. Six horses, with a circular saw, driven by means of a good horse-power, will saw five times six, or thirty cords, working the same length of time. In this case the loss by friction is about equal to the additional force required for attendance on the machine.

Again: a man will cut with a cradle two and a half acres of wheat in a day. A two-horse reaper should therefore cut, at the same rate, ten times two and a half, or twenty-five acres. This has not yet been accomplished. We may hence infer that the machinery for reaping has been less perfected than for sawing wood. It should, however, be remembered, that great force is exerted, and for many hours in a day, in cutting wheat with a cradle, and therefore a little less than twenty-five acres a day may be regarded as the maximum attainment of good reaping-machines, when they shall become perfected.

Applying the same mode of estimate, a horse-cultivator will do the work of five men with hoes, and a two-horse plow the work of ten men with spades. A horse-rake accomplishes more than five men, because human force is not strongly exerted with the hand-rake.

In using different tools, the degree of force or pressure applied to them varies greatly with the mode in

which the muscles are exerted. The following table gives the results of experiments with human strength, variously applied, for a short period:

	Force of the hands on the tool.	Force of the tool on the object.
With a drawing-knife	100 lbs.	100 lbs.
" a large auger, both hands	100 "	about 800 "
" a screw-driver, one hand	84 "	250 "
" a bench-vice handle	72 "	about 1000 "
" a windlass, with one hand	60 "	180 to 700 "
" a hand-saw	36 "	36 "
" a brace-bit, revolving	16 "	150 to 700 "
Twisting with thumb and fingers, button-screw, or small screw-driver	14 "	14 to 70 "

The force given in the last column will, of course, vary with the degree of leverage applied; for example, the arms of an auger, when of a given length, act with a greater increase of power with a small size than with a large one. This degree of power may be calculated for an auger of any size, by considering the arms as a lever, the centre screw the fulcrum, and the cutting-blade as the weight to be moved. The same mode of estimate will apply to the vice-handle, the windlass, and the brace-bit.

Every one is aware that a heavy weight, as a pail of water, is easily lifted when the arm is extended downward, but with extreme difficulty when thrown out horizontally. In the latter case, the pail acts with a powerful leverage on the elbow and shoulder-joint. For this reason, all kinds of hand-labor, with the arms pulling toward or pushing directly from the shoulders, are most easily performed, while a motion sidewise or at right angles to the arm is far less effective. Hence great strength is applied in rowing a boat or in using

a drawing-knife, and but little strength in turning a brace-bit or working a dasher-churn. Hence, too, the reason that, in turning a grindstone, the pulling and thrusting part of the motion is more powerful than that through the other parts of the revolution. This also explains why two men, working at right angles to each other on a windlass, can raise seventy pounds more easily than one man can raise thirty pounds alone. This principle should be well understood in the construction or selection of all kinds of machines for hand labor.

SECTION VI.

MODELS OF MACHINES.

Serious errors might often be avoided, and sometimes gross impositions prevented, by understanding the difference between the working of a mere model, on a miniature scale, and the working of the full-sized machine. It is a common and mistaken opinion that a well-constructed model presents a perfect representation of the strength and mode of operation of the machine itself.

When we enlarge the size of any thing, the *strength* of each part is increased according to the square of the diameter of that part; that is, if the diameter is twice as great, then the strength will be four times as great; if the diameter is increased three times, then the strength will be nine times, and so on. But the *weight* increases at a still greater rate than the strength, or according to the *cube* of the diameter. Thus, if the diameter be doubled (the *shape* being similar), the

weight will be eight times greater; if it be tripled, the weight will be twenty-seven times greater. Hence, the larger any part or machine is made, the less able it becomes to support the still greater increasing weight. If a model is made one tenth the real size intended, then its different parts, when enlarged to full size, become one hundred times stronger, but they are a thousand times heavier, and so are all the weights or parts it has to sustain. All its parts would move ten times faster, which, added to their thousand-fold weight, would increase their inertia and momentum ten thousand times greater. For this reason, a model will often work beautifully when made on a small scale; but when enlarged, the parts become so much heavier, and their momentum so vastly greater, from the longer sweep of motion, as to fail entirely of success, or to become soon racked to pieces.

This same principle is illustrated in every part of the works of creation. The large species of spiders spin thicker webs, in comparison with their own diameter, than those spun by the smaller ones. Enlarge a gnat until its whole weight be equal to that of the eagle, and, great as that enlargement would be, its wing will scarcely have attained the thickness of writing-paper, and, instead of supporting the weight of the animal, would bend down from its own weight. The larger spiders rarely have legs so slender in form as the smaller ones; the form of the Shetland pony is quite different from that of the large cart-horse; and the cart-horse has a slenderer form than the elephant.

The common flea will leap two hundred times the length of its own body, and the remark has been some-

times made that a man equally agile, with his present size, would vault over the highest city-steeple, or across a river as wide as the Hudson at Albany. Now, if the flea were increased in size to that of a man, it would become a hundred thousand times stronger, but thirty million times heavier; that is, its weight would become three hundred times greater than its corresponding strength. Hence we may infer that the enlarged flea would be no more agile than a man; or that, if a man were proportionately reduced to the size of a flea, he could leap to as great a distance.

All this serves to illustrate in a striking manner the distinction between models and machines.

PART II.

HYDRODYNAMICS.*

HYDROSTATICS† treats of the weight and pressure of liquids when not in motion; HYDRAULICS,‡ of liquids in motion, as, conducting water through pipes, raising it by pumps, &c.; and HYDRODYNAMICS includes both, by treating of the *forces* of the liquids, whether at rest or in motion.

CHAPTER I.

HYDROSTATICS.

SECTION I.

UPWARD PRESSURE.

A REMARKABLE property of liquids is their pressure *in all directions*. If we place a solid body, as a stone, in a vessel, its weight will only press upon the bottom; but if we pour in water, the water will not only press upon the bottom, but against the sides. For, bore a hole into the side, and the side pressure will drive out the water in a stream; or, bore small holes into the sides and bottom of a tight wooden box, stopping them

* From two Greek words, *hudor*, water, and *dunamis*, power.

† From two Greek words, *hudor*, water, and *statos*, standing, or at rest. ‡ From two Greek words, *hudor*, water, and *aulos*, a pipe.

with plugs; then press this box, empty, bottom downward, into water, allowing none to run in at the top. Now draw one of the side plugs, and the water will be immediately driven into the box by the pressure outside. If a bottom plug be drawn, the water will immediately spout up into the box, showing the pressure *upward* against the bottom. Hence the pressure in *all directions*, upward, sideways, and downward, is proved.

The upward pressure of liquids may be shown by pouring into one end of a tube, bent in the shape of the letter U, enough water to partly fill it; the upward pressure will drive it up the other side till the two sides are level.

On this principle depends the art of conveying water in pipes under ground, across valleys. The water will rise as high on the opposite side the valley as the spring which supplies it. The ancient Romans, who were unacquainted with the manufacture of strong cast-iron pipes, conveyed water on lofty aqueducts of costly masonry, built level across the valleys. Even at the present day, it has been deemed safest to build level aqueducts for conveying great bodies of water, as in very large pipes the pressure would be enormous, and might result in violent explosions.

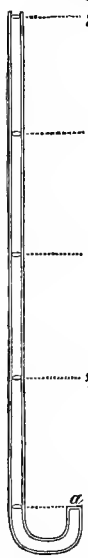
If the valleys are deep, the pipes must be correspondingly strong, because, the higher the head of water, the greater is the pressure. For the same reason, dams and large cisterns should be strongest at bottom. Reservoirs made in the form of large tubs require the lower hoops to be many times stronger or more numerous than the upper.

MEASUREMENT OF PRESSURE AT DIFFERENT HEIGHTS.

The amount of pressure which any given height of water exerts upon a surface below may be understood by the following simple calculation:

If there be a tube one inch square (with a closed end), half a pound of water poured into it will fill it to a height of fourteen inches;* one pound will fill it twenty-eight inches; two pounds, fifty-six inches; ten pounds, twenty-three feet; twenty pounds, forty-six feet, and so on. Now, as the side pressure is the same as the pressure downward for the same head of water, the same column will, of course, exert an equal pressure on a square inch of the *side* of the tube. Or, if the tube be bent, as shown in the annexed figure (*Fig.* 149), the pressure upward on the end of the tube, at *a*, will be the same for the various heights.

Fig. 149.



Now, as the pressure of a column fifty feet high is about twenty-two pounds on a square inch, the pressure on the *four* sides is equal to eighty-eight pounds for one inch in length. Hence the reason that considerable strength is required in tubes which have much head of water, to prevent their being torn open by its force.

* This is nearly correct, for a cubic foot (or 1728 cubic inches) of water weighs 62 lbs. Consequently, one pound will be 27.9 cubic inches, and will fill the tube nearly 28 inches high.

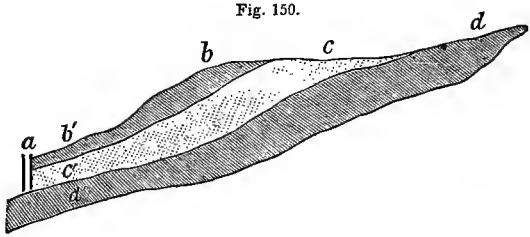
DETERMINING THE STRENGTH OF PIPES.

The question may now arise, and it is a very important one, How thick must be a lead tube of this size to prevent danger of bursting with a head of fifty feet, or of any other height? To answer it, let us turn to the table of the *Strength of Materials* in a former part of this work, where we find that a bar of cast lead one fourth of an inch square will bear a weight of fifty-five pounds. If the tube be only one sixteenth of an inch thick, one inch of one of its sides will possess an equal strength, that is, will bear fifty-five pounds only, and the tube would consequently burst with fifty feet head. If one tenth of an inch thick, the tube would just bear the pressure, and, to be safe, should be about twice as thick, or one fifth of an inch. Half this thickness would be sufficient for twenty-five feet of water, which would require to be doubled for one hundred feet. A round tube, one inch in diameter, having less surface to its sides, would be about one third stronger. A tube twice the diameter would need twice the thickness; or if less in diameter, a proportionate decrease in thickness might take place. If, instead of cast lead, milled lead were used, the tube would be nearly four times as strong, according to the table of the strength of materials already referred to.

SPRINGS AND ARTESIAN WELLS

Result from the upward pressure of water. Rocks are usually arranged in inclined layers (*Fig.* 150, p. 180), and when rain falls upon the surface, as at *c d*, it sinks down in the more porous parts between these layers,

Fig. 150.

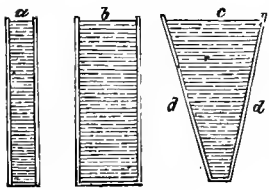


to *c*. If the layers happen to be broken in any place below, the water finds its way up through the crevices by the pressure of the head above, and forms springs. If there are no openings through the rocks, deep borings are sometimes made artificially, through which the water is driven up to the surface, as at *a*, forming what are termed *Artesian Wells*. The head of water which supplies them may be many miles distant, the place of discharge being on a lower level. It has sometimes been found necessary to bore more than a thousand feet downward before obtaining water which will flow out freely at the surface of the earth.

SECTION II.

DETERMINING THE PRESSURE ON GIVEN SURFACES.

Fig. 151.

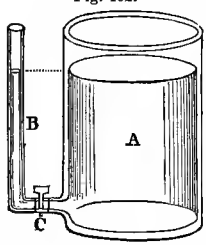


The pressure of liquids upon any given surface is always exactly in proportion to the height, no matter what the shape of the vessel may be. If, for instance, the vessel *a* (*Fig.* 151), be one inch in diameter, and the vessel *b* be three inches in diameter,

the water being equally high in both, the pressure on the whole bottom of *b* will be nine times as great as on the bottom of *a;* or any one inch of the bottom of *b* will receive as great a pressure as the bottom of *a*. Again, if the vessel *c*, broad at the top, be narrowed to only an inch in diameter at bottom, the pressure upon that inch will still be the same, most of the weight of its contents resting against the sides, *d d*.

If the vessel, A (*Fig.* 152), be filled with water to a height of fourteen inches, the pressure will be half a pound on every square inch of the bottom, or upon every square inch of the sides fourteen inches below the surface. If the tube, C, be an inch square, the water will be driven into it with a force of half a pound, and will press with that force against the one-inch surface of the stop-cock, C. If the tube, B, be now filled to an equal height, the same force will be exerted against the other side. To prove this, let the stop-cock be opened, when the two columns of water will remain at an exact level.

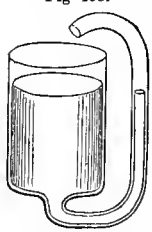
Fig. 152.



If enough water be now poured into the tube, B, to fill it to the top, it will immediately settle down on a level with the water in A, raising the whole surface in the latter. This result has seemed very strange to many, who can not conceive how a small column of water can be made to balance a large one, and it has been therefore termed the *Hydrostatic Paradox*. But the difficulty entirely vanishes, and ceases to appear a paradox, when we remember that the water in the

larger vessel rises as much more slowly than it descends in the smaller, as the large one exceeds the smaller; thus acting on the principle of virtual velocities in precisely the same manner that a heavy weight on the short end of a lever is upheld by a small weight on the long end. The great mass of water is supported directly by the bottom of A, in the same way that nearly all the weight on the lever is supported by the fulcrum. A man who was seeking a solution to the absurd mechanical problem of perpetual motion, and who supposed that the large mass in A would overbalance the small column in B, and drive it upward, constructed a vessel in the form shown in *Fig.* 153, so that the small column, when forced upward, would flow back into the larger vessel perpetually. He was, however, greatly surprised to see the fluid in both divisions settle at the same level.

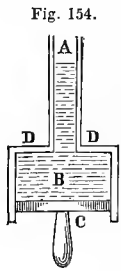
Fig 153.



Attempted Perpetual Motion.

This principle may be further explained by the following experiment: A B (*Fig.* 154) represents the inside of a metallic vessel, with a bottom, C, which slides up and down, water-tight. If water be poured in to fill the lower or larger part only, it will be found to press on the sliding bottom with a force exactly equal to its own weight; that is, if there is a pound of water, it will press on the botton with a force equal to one pound. Now, if the bottom be pushed upward, so as to drive the water into the narrow part of the vessel, the pressure upon the bottom becomes instantly

Fig. 154.

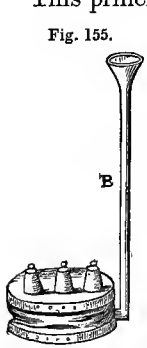


much greater, or equal to many pounds, the water being the same in quantity, but with a much higher head than before. Suppose the narrow part of the vessel is twenty times smaller than the larger part, then, in pushing the bottom up one inch, the water is driven twenty inches upward in the tube. So then, according to the rule of virtual velocities, it will require twenty times the force, because it moves upward twenty times faster.* This, then, is precisely similar to the instance where a pound on the longer end of a steelyard balances twenty pounds on the shorter end. In this instance, the upper parts, D D, of the vessel operate as the fulcrum of a lever, and offer resistance to the sliding part as soon as the water begins to ascend the tube.

HYDROSTATIC BELLOWS.

This principle is shown in the *Hydrostatic Bellows* (*Fig.* 155), which consists of two round pieces of board, connected by a narrow strip of strong leather; into it is inserted a long narrow tube, B, with a small funnel, *e*, at the top. When water is poured into this tube, it will raise a weight as much greater than the weight of the water in the tube as the surface of the upper board exceeds the cross-section of the tube. Thus, if a pound of water fills a tube half an inch in diameter, and the bellows is two feet in diameter, then this pound will

Fig. 155.



Hydrostatic Bellows.

* The pressure will be as great upon the bottom as if the vessel continued a uniform size all the way up, as shown by the dotted lines.

raise more than two thousand pounds on the bellows (if it is strong enough), because the surface of the bellows is more than two thousand times greater.

In the same way, a strong, iron-bound hogshead may be burst with the weight of a single gallon of water by pouring it into a long and narrow tube set upright into the bung of the hogshead. If, for instance, the inner surface of the hogshead be 20 square feet, or 2880 square inches, a tube of water 23 feet high will press with a force of 10 pounds on every square inch, or equal to a force of 28,800 pounds, or 14 tons, on the whole surface.

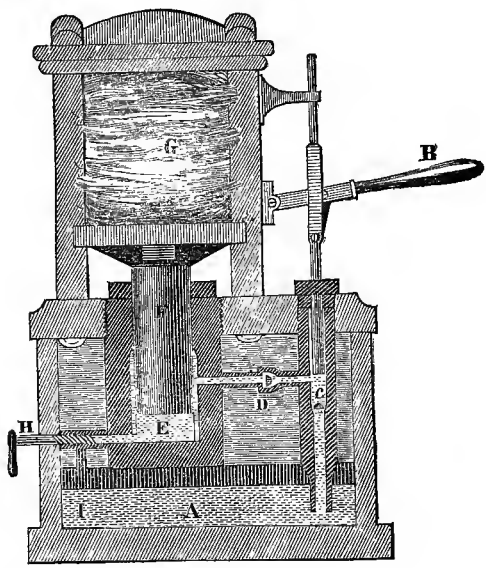
HYDROSTATIC PRESS.

The *Hydrostatic Press* owes its extraordinary power to a similar principle; but, instead of a bellows, there is a moving piston in a strong metallic cylinder; and instead of being worked by the mere weight of the water, it is driven into the cylinder by means of the lever of a powerful forcing-pump. An instrument of this sort, possessing enormous power, was used to elevate the great tubular iron bridge in England. It was found necessary to make the sides of the cylinder into which the water was driven no less than eleven inches thick, of solid iron; and so great was the pressure given to the confined water, that it would have forced it up through a tube higher than the summit of Mont Blanc. In the port of New York, vessels of a thousand tons burden have been lifted by the hydrostatic press.

This machine is applied in compressing hay, cotton, and other bulky substances into a compact form, so that they may occupy but little space for conveyance

to distant markets. The following figure (*Fig.* 156) exhibits the different parts of this powerful machine.

Fig. 156.



Hydrostatic Press.

A is a cistern to supply water, which is raised by working the handle, B, of the forcing-pump; the water passes through the valve, C, opening upward, and through the spring valve, D, opening toward the large cylinder, E. Being thus driven into the space, E, it raises the piston, F, and exerts a prodigious pressure upon the mass of hay or cotton, G. The piston is lowered by turning the screw, H, which allows the water to pass back into the cistern at I. In the figure the hay is shown as visible to the sight, in order to represent the whole more plainly; but in practice it is

thrown into a square box or chamber of strong plank, of the size of the intended bundle. One side is hung upon stout hinges, and is opened for the removal of the hay when the pressing is completed.

To estimate the power of this machine, divide the square of the diameter of the piston, F, by the square of the diameter of the piston of the forcing-pump, and multiply the quotient by the power of the lever, B. For example, suppose the piston, F, is 16 inches in diameter, and the piston of the forcing-pump is 2 inches in diameter; then the square of 16 is 256. Divide this by 4, the square of 2, and the result will be 64. If the lever, B, increases the power five times, the whole power of the machine will be 320; that is, a force of one pound applied to the lever will raise the large piston with a force equal to 320 pounds; or, if a force of 100 pounds be given to the lever, the power will be 32,000 pounds, or 16 tons. Reducing the diameter of the smaller piston to half an inch, and increasing the force of the lever to twenty times, the whole power exerted will be thirty-two times as great, or equal to 960 tons. In ordinary practice, it is more convenient and economical to reduce the diameter of the larger piston to a few inches only, making the forcing-pump correspondingly small, the power depending entirely on the disproportion between them. Such presses may be worked rapidly by horse, water, or steam power.

One great advantage which the hydrostatic press possesses over those worked by screws results from the little friction among liquids, nearly the only friction existing in the whole machine being that of the

two pistons, which is comparatively small. Another is the smallness of the compass within which the whole is comprised; for a man might, with one not larger than a tea-pot, standing before him on a table, cut through a thick bar of iron with as much ease as he could chip pasteboard with a pair of shears.

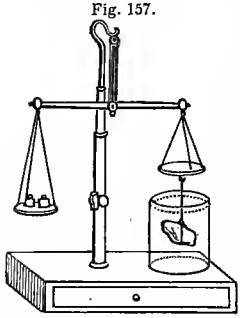
SECTION III.

SPECIFIC GRAVITIES.

In connection with Hydrostatics, the subject of the specific gravities of bodies is one of importance. The specific gravity of a substance is its *comparative weight* with some other substance, an equal bulk of each being taken. Water is usually the standard for comparison.

To ascertain the specific gravity, weigh the body both in and out of water, and observe the difference; then divide the whole weight by this difference, and the quotient will be the specific gravity of the body.

Fig. 157.



Instrument for taking Specific Gravities.

For example, if a stone weighs 12 lbs. out of water and 7 lbs. in water, divide 12 by 5, and the quotient is 2.4, which shows that the stone is $2\frac{4}{10}$ times heavier than water. *Figure* 157 shows the mode of weighing the body in water, by suspending it beneath a balance on a hair or thread.

It was in a similar way that Archimedes succeeded in detecting the suspected fraud in the manufacture of the gold-

en crown of the ancient king of Syracuse. He first weighed it, and then found that it displaced more water when plunged in a vessel just filled, than a piece of pure gold, and also that it displaced less than silver, whence he inferred the mixture of these two metals.

When the specific gravity of a substance lighter than water is to be ascertained, it is loaded down by a weight, so as to sink in water, for which allowance is made in the calculation. A very simple way to determine this in different kinds of wood is to form them into rods or sticks of uniform size throughout, and then to observe what portion of them sink when placed endwise in water.

A knowledge of the specific gravities of various substances becomes useful in many ways, among which is ascertaining the weight of any structure, machine, or implement, according to the material used in its manufacture; determining the cost, by the pound, of such material; or knowing the bulk or size of any load for a team. The latter may often become of great use in ordinary practice, by enabling the teamster to calculate beforehand the amount of load to give his horses, whether in timber, plank, brick, lime, sand, or iron, without first subjecting them to overstraining exertions in consequence of error in random guessing.

Tables of specific gravities, for this purpose, and weights of a cubic foot of different substances, are given in the Appendix.

CHAPTER II.

HYDRAULICS.

SECTION I.

VELOCITY OF FALLING WATER.

Liquids in motion are subject to the same laws as solids in motion. Falling water increases in velocity at the same rate that the motion of falling solids is accelerated, as already explained under the head of *Gravitation.* Thus a perpendicular stream of water descends one foot in a quarter of a second, four feet in half a second, nine feet in three fourths of a second, and sixteen feet in one second. Like falling solids, the velocity at the end of the first quarter will be eight feet per second; at the end of the second quarter, sixteen feet per second; at the end of the third quarter, twenty-four feet per second; and at the end of the fourth quarter, thirty-two feet per second.

Now, if there be an *orifice* made in the side of a vessel of water, the water will spout out with the same swiftness as if it fell perpendicularly from an equal height, were it not retarded a little by friction. For example, if the head of water is one foot above the orifice, the velocity would be at the rate of eight feet per second, but for friction, which reduces it to about five and a half feet* per second. The velocity for any other height of head may be easily found by deducting the same proportionate rate from the velocity of a

* Or, more accurately, 5.4 feet per second.

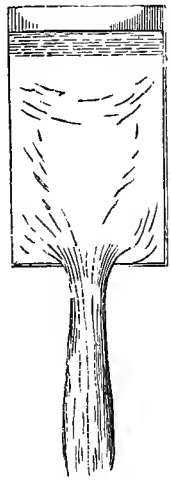
falling body. Thus, for example, if the head be sixteen feet, the speed would be thirty-two feet (as shown under *Gravitation*), from which, deducting the friction, the real velocity would be about twenty-two feet per second.

It has been already shown that the velocity of a falling body increases at the same rate as the increase in the time of falling; for instance, the speed is twice as great in two seconds as in one; three times as great in three seconds; four times as great in four seconds, and so on. But the *distance fallen through* increases as the *square* of the time; that is, it is four times as great in two seconds, nine times as great in three seconds, sixteen times as great in four seconds, &c. Thus we see that, in order to produce a two-fold velocity, a four-fold height is necessary, &c. So also in the escape of water under a head: to double the velocity of the stream, the head must be four times as high; to triple it, the head must be nine times as high, &c.

DISCHARGE OF WATER THROUGH ORIFICES AND PIPES.

The discharge of water from a vessel is greatly influenced by the nature of the orifice through which it flows. If, for example, a vessel or cistern have a thin bottom of tin, with a smooth circular hole, we might naturally suppose that the discharge would be as easy as it could be made, and that water would pass as rapidly through it as through any orifice of an equal size. But this is not the fact. As the particles approach this orifice, their motion throws them across, and they partly obstruct the opening; it will be seen that they converge toward a point just under the orifice, where

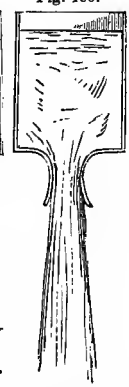
Fig. 158.



the stream will be considerably contracted (*Fig.* 158). If a short tube be inserted into the hole (the head being the same), this crossing of particles will be partly prevented, and the liquid will flow more rapidly. The greatest effect is produced when the tube is twice as long as its diameter (*Fig.* 159). If the tube be enlarged at its upper and lower end, similar to the form of the contracted stream of water in *Fig.* 158, the quantity discharged is greatly increased (*Fig.* 160).

Fig. 159.

Fig. 160.



When water flows down an inclined plane, the same law applies as to the motion of a solid body rolling down a plane. The velocity increases as the square of the distance, and is the same as the velocity of a body falling freely downward from a height equal to the perpendicular height of the plane. Unless the stream, however, is very large, its speed is quickly diminished by the friction of its channel,* until this friction becomes as great as the descending force, after which the motion becomes uniform. Hence the reason that large streams, with an equal degree of descent, flow so much more rapidly than small ones, the gravitating force being so much greater that friction has a less retarding effect upon them.

* Which increases as the square of the velocity.

In pipes which wholly surround the flowing stream, the friction becomes still greater, and the difficulty is only obviated by making the pipe of larger dimensions than would otherwise be necessary, so as to allow a free passage of a sufficient quantity of water through the centre of the tube, while a ring or hollow cylinder of water is nearly at rest all around it. The tables in the Appendix exhibit this decreased velocity in tubes of various sizes.

SECTION III.

VELOCITY OF WATER IN DITCHES.

It is often of great practical utility to know what amount of water may be carried off in draining or supplied in irrigation by channels of any given size and descent. The following rule will apply to all cases, from the plow-furrow to the mill-race, or even to the large river, and may be used by any boy who understands common arithmetic, and which is illustrated and made plain by the example that follows the rule.

To ascertain the mean (or average) velocity of water in a straight channel of equal size throughout:

Let f = the fall in two miles in inches;

Let d = the hydraulic mean depth;

Let v = the velocity in inches per second;

then the rule is thus expressed, $v = 0.91\sqrt{fd}$, or, in plain words, the velocity is equal to the hydraulic mean depth multiplied by the fall, with the square root of this product extracted, and then multiplied by 0.91.

The "*hydraulic mean depth*" is found by dividing the cross-section of the channel by the *perimeter* or

border. The perimeter is the aggregate breadths of the sides and bottom of the channel.

The rule will be rendered quite plain by an example. Suppose a smooth furrow is cut six inches wide and four inches deep, with perpendicular sides, and that it descends one inch in a rod; to find the quantity of water that will flow through it. One inch fall in a rod is 320 inches in a mile, or 640 in two miles. The perimeter in contact with the water will be six inches on the bottom, and four inches in each side $=14$ inches. The area of the cross-section will be 6 times $4=24$, which divided by 14, the perimeter, gives $1.7=$ the hydraulic mean depth. Then, by applying the preceding rule:

$v=0.91\sqrt{640\times1.7}$, or $v=0.91\times33=30$ inches,

the velocity per second, which would be about three gallons per second, or three hogsheads per minute.

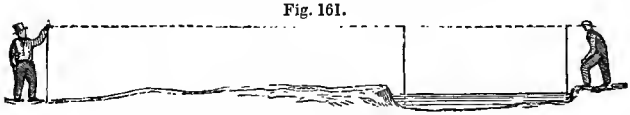
An open ditch, therefore, with smooth sides, conveying a stream of this size, would carry off in one hour, from an acre of land, all the water which might fall by half an inch of rain during the wet season; for half an inch of rain would be 180 hogsheads per acre, which would pass off in one hour; or it would supply in one hour, by the process of irrigation, as much water as a heavy shower of half an inch. Where the descent is greater, the increased quantity may be readily calculated by the rule given. The capacity of smooth-sided underground channels may be determined in the same way; but if built of rough stones, great allowance must be made, as they will retard the flow of water.

In common practice, too, even with straight, open ditches, the velocity will be much diminished by the rough sides.

LEVELING INSTRUMENTS.

The simplest mode of *leveling*, or ascertaining the slope for ditches, is to cut a few yards of the ditch so that water may stand in it, and then to set two sticks perpendicularly, both rising to an equal height above the surface. The sticks should be measured at equal distances from the top downward and marked, and

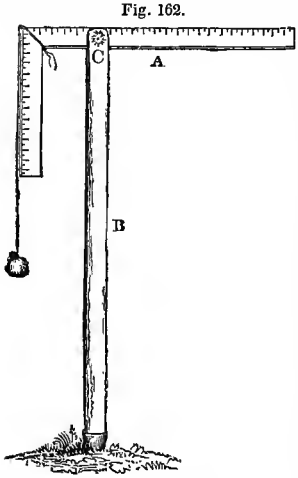
Fig. 161.



Simple method of taking levels.

then pressed into the earth till the water reaches the mark. The level may then be determined with much accuracy by "sighting" over the tops of these sticks.

Fig. 162.



Simple Leveling Instrument.

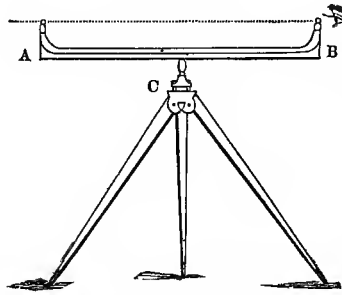
Figure 161 exhibits this arrangement. The shorter the sticks, and the longer the piece of water, the less will be the liability to error.

The following simple mode may be sufficiently accurate where the descent of the ditch is considerable. A (*Fig.* 162) is a common square, placed in a slit in the top of the stake, B. By means of a plumb-line, the square is brought to a level, when a thumb-screw at C fixes it fast. If the square

is two feet long, and is so carefully adjusted by means of the plumb-line as not to vary more than the twentieth of an inch from a true level, which is easily accomplished, then a twentieth of an inch in two feet will be one inch in forty feet, a sufficient degree of accuracy for many cases.

Where greater accuracy is required, as in long and nearly level ditches, the "water level" may be used.

Fig. 163.



Common Leveling Instrument.

It may be made of a lead tube about three feet long, bent up an inch or two at each end, and stiffened by fastening to a wooden bar, A, B (*Fig.* 163). Into each end is cemented, with sealing-wax, a small and thin phial with the bottom broken off, so that when the tube is filled with water it may rise freely into the phials. If the tube be now filled with water colored with cochineal or any dye-stuff, and then placed upon the tripod, C, by looking across the two surfaces of liquid in the phials, an accurate level may be obtained. When not in use, a cork is placed into each phial. "Sights" of equal height, fastened to pieces of cork floating on the water, as shown in *Fig.* 164, give a more distinct line for the eye. The sights are formed of fine threads or hairs stretched across the square openings. To ascertain whether these threads are both of equal heights above the water, let a mark be made

Fig. 164.

where they intersect some distant object; then reverse the instrument, or turn it end for end, and observe whether the threads cross the same mark. If they do, the instrument is correct; but if they do not, then one of the sights must be raised or lowered until it becomes so.

In laying out canals and rail-roads, where extreme accuracy is needed, the *spirit-level* attached to a telescope is used. So great is the perfection of this instrument, that separate lines of levels have been run with it for sixty miles without varying two thirds of an inch for the whole distance.

The use of a cheap and simple instrument to determine the position and descent of ditches with ease and precision, before commencing with the spade, will save a vast amount of the trouble and expense which those often meet with whose only method is to "*cut and try.*"

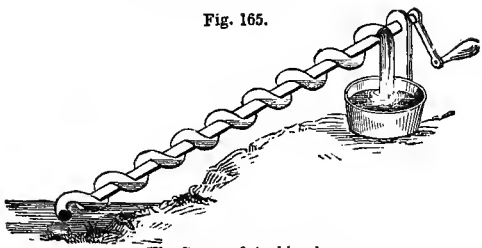
SECTION III.

HYDRAULIC MACHINES.

ARCHIMEDEAN SCREW.

Machines for raising water are of frequent use on every farm. One of the simplest contrivances for this purpose is *the Screw of Archimedes.* It may be easily made by winding a lead tube around a wooden cylinder or rod (*Fig.* 165), in the form of a screw. When placed in an inclined position, with one end in water, and made to revolve, the water resting at the lower side of each turn of the screw is gradually carried from one end to the other, and discharged at the upper extremi-

Fig. 165.



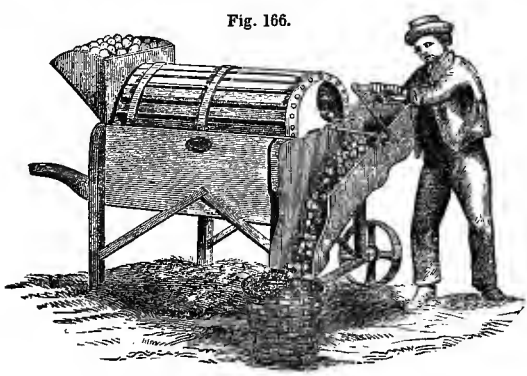
The Screw of Archimedes

ty. Its simplicity and small liability to get out of order renders the Archimedean Screw sometimes useful where water is to be raised from an open stream to a short distance, as for irrigation, the motion being easily imparted to it by means of a small water-wheel driven by the stream.

ARCHIMEDEAN ROOT-WASHER.

This principle has been successfully applied in the *Archimedean Root-washer* (*Fig.* 166). The roots to

Fig. 166.



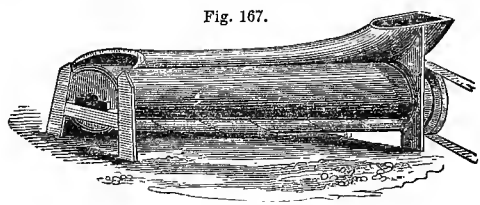
Croskill's Archimedean Root-washer.

be washed are first delivered into a hopper, from which

they pass into an inclined cylinder made of strips of wood with grate-like openings. The cylinder has two portions separated by a partition, in the first of which they remain while the handle is turned for washing them. As soon as the washing is finished, the motion of the handle is reversed, which throws them into the other part, which has a spiral partition, along which they pass till they drop into a spout outside.

The same principle is adopted in the horizontal corn-sheller, shown by the annexed figure (*Fig.* 167), al-

Fig. 167.



Corn-shelier.

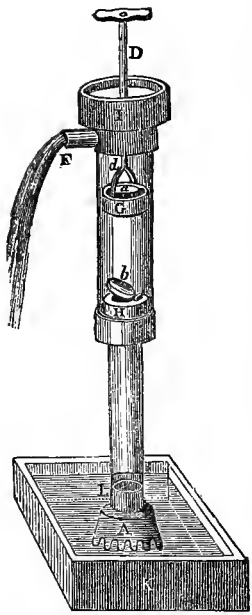
though this machine has no connection with hydraulics. The corn in the ear is thrown into the hopper at one end, and is quickly separated from the cob by rows of teeth revolving in a concave bed and set spirally, which, by this arrangement, carry along the cobs and eject them from the other end. This is a good corn-shelling machine for horse-power.

The sausage-mincing machine operates on a similar principle.

PUMPS.

Great improvement has been made in the *common pump* for farms within the past ten years. The best cast-iron pumps, made almost wholly of this metal, far

Fig. 168.

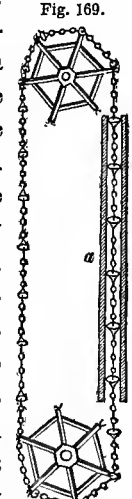


Common Pump : b, lower or fixed valve, G, piston with valve, a, opening upward; D d, piston-rod; F, spout.

exceed in durability and ease of working those formerly constructed of wood, and excel all others in cheapness. *Fig.* 168 exhibits the working of the common pump, the water first passing through the fixed valve below, and then through the one in the piston; both opening upward, it can not flow back without instantly shutting them. The water is driven up by the pressure of the atmosphere, explained in the next chapter.

The most perfect pump, perhaps, in present use, is the best-constructed *Chain Pump*, a cross-section of one of which is here shown (*Fig.* 169). The chain is made to revolve rapidly on the angular wheel by means of a winch attached to the upper one, and being furnished with a regular succession of metallic discs which nearly fit the bore in the tube, *a*, the water is carried up in large quantities. When the motion is discontinued, the water settles down again into the well, and consequently this pump is not liable to accident by freezing. By sweeping rapidly through the water, it pre-

Fig. 169.



Chain Pump.

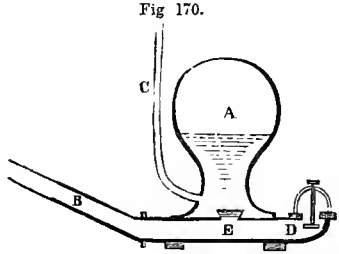
serves it in better condition, and prevents stagnation. The friction being very small, it will last a long time without wearing out.

THE WATER-RAM.

One of the most ingenious and useful machines for elevating water is the *Water-ram.* It might be employed with great advantage on many farms, were its principle and mode of action more generally understood. By means of a small stream, with only a few feet fall, a current of water may be driven to an elevation of fifty to a hundred feet above, and conveyed on a higher level to pasture-fields for irrigation, or to cattle-yards for supplying drink to domestic animals, or to the kitchen of dwellings for culinary purposes.

Its power depends on the momentum of the stream. Its principal parts are the reservoir or air-chamber, A (*Fig.* 170), the supply-pipe, B, and the discharge pipe, C. The running stream rushes down the supply-pipe, B, and, striking the waste valve, D, closes it. The stream being thus suddenly stopped, its momentum opens the valve, E, upward, and drives the water into the reservoir, A, until the air within, being compressed into a smaller space, by its elasticity bears down upon the water, and again closes the valve, E. The water in the supply-pipe, B, has by this time expended its momentum and stopped

Fig 170.



Water-ram.

running; therefore the valve, D, drops open again, and permits it to escape. It recommences running, until its force again closes the waste valve, D, and a second portion of water is driven into the reservoir as before, and so it repeatedly continues. The great force of the compressed air in the reservoir drives the water up the discharge-pipe, C, to any required height or distance.

The mere *weight* of the water will only cause it to rise as high as the fountain-head; but like the momentum of a hammer, which drives a nail into a solid beam, which a hundred pounds would not do by pressure, the *striking force* of the stream exerts great power.

The discharge-pipe, C, is usually half an inch in diameter, and the supply-pipe should not be less than an inch. A fall of two or three feet in the stream, with not less than half a gallon of water per minute, with a supply-pipe forty feet long, will elevate water to a height as great as the strength of common half-inch lead pipe will bear.* The greater the height in proportion to the fall of the stream, the less will be the quantity of water elevated as compared with the quantity flowing in the stream.

Unlike a pump, there is no friction or rubbing of parts in the water-ram, and it will act for years without repairs, continuing through day and night its

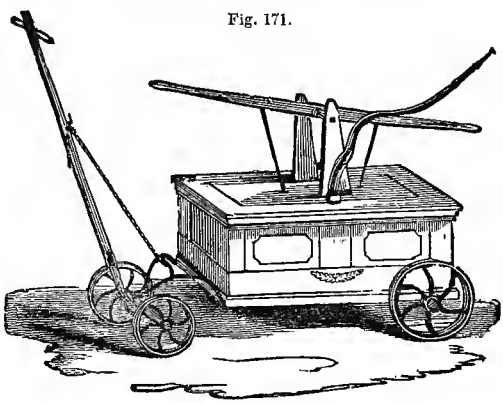
* When water is raised to a considerable elevation by means of the water-ram, the reservoir must possess great strength. If the height be one hundred feet, the pressure, as shown on a former page, is about forty-four pounds to the square inch. With an internal surface, therefore, of only two square feet, the force exerted by the column of water, tending to burst the reservoir, would be equal to more than twelve thousand pounds.

constant and regular pulsations, unaltered and unobserved.

WATER-ENGINES,

including those for extinguishing fires and for irrigating gardens, are constructed on a principle quite similar to that of the water-ram. Instead, however, of compressing the air, as in the ram, by the successive strokes of a column of running water, it is accomplished by means of a forcing-pump, driving the water into the reservoir, from which it is again expelled with great power by means of the elasticity of the compressed air. *Fig.* 171 represents a garden-engine,

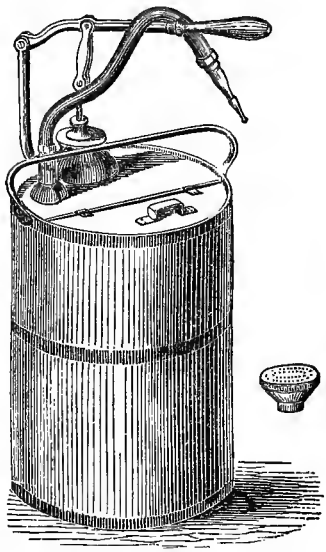
Fig. 171.



Garden-engine.

movable on wheels, which may be used for watering gardens, washing windows, or as a small fire-engine. *Fig.* 172 (at the head of the opposite page) is another of smaller size, for the same purpose, and in a very neat and compact form, the working part being within the cylindrical case.

Fig. 172.

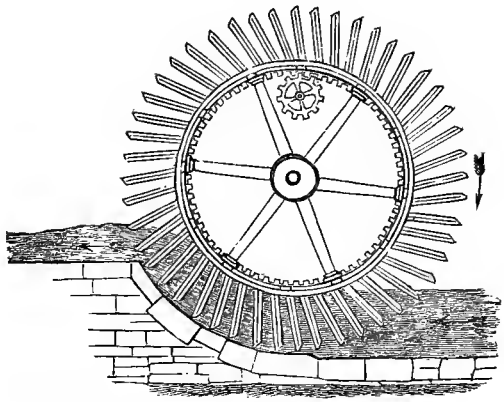


Cylindrical Garden-engine.

THE FLASH-WHEEL

is employed with great advantage where the quantity of water is large and is to be raised to a small height. It is like an undershot-wheel with its motion reversed (*Fig.* 173, p. 204), where the arrows show the direction of the current when driven upward. It must, of course, be made to fit the channel closely, without touching and causing friction. In its best form its paddles incline backward, so as to be nearly upright at the time the water is discharged from them into the upper channel. It has been much used in Holland, where it is driven by wind-mills, for draining the surface-water off from embanked meadows. In England

Fig. 173.



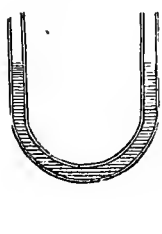
Flash or fen wheel for raising water rapidly short distances.

it has been driven by steam-engines; and in one instance, an eighty-horse-power engine, with ten bushels of coal, raised 9840 tons of water six feet and seven inches high in an hour. This is equal to more than 29,000 lbs. raised one foot per minute by each horse-power, showing that very little force is lost by friction in the use of the flash-wheel.

SECTION IV.

WAVES.

Fig. 174.



NATURE OF WAVES.

An inverted syphon, or bent tube like that shown in *Fig.* 174, may be used to exhibit the principle on which depends the motion of the waves of the sea. The action of the waves on shores

and banks, and the inroads which they make upon farms situated on the borders of lakes and large rivers, present an interesting subject of inquiry.

If the bent tube (*Fig.* 174) be nearly filled with water, and the surface be driven down in one branch by blowing suddenly into it, the liquid will rise in the other branch. The increased weight or head of this raised column will cause it to fall again, its momentum carrying it down below a level, and driving the water up the other branch. The surfaces will, therefore, continue to vibrate until the force is spent. The rising and falling of waves depend on a similar action. The wind, by blowing strongly on a portion of the water of the lake or sea, causes a depression, and produces a corresponding rise on the adjacent surface. The raised portion then falls by its weight, with the added force of the wind upon it, until the vibrations increase into large waves.

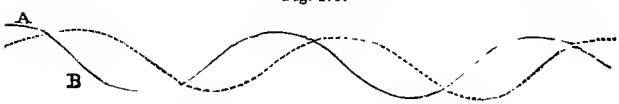
THE WATER NOT PROGRESSIVE.

The waves thus produced have a progressive motion (for reasons to be presently shown), as every one has observed. A curious optical deception attending this advancing motion has induced many to believe that the water itself is rolling onward; but this is not the fact. The boat which floats upon the waves is not carried forward with them; they pass underneath, now lifting it on their summits, and now letting it sink into the hollows between. The same effect may be observed with the water-fowl, which sits upon the surface. It often happens, indeed, that the waves on a river roll in an opposite direction to the current itself.

If a cloth be laid over a number of parallel rollers so far apart as to allow the cloth to fall between them, and a progressive motion be then given to them, the cloth remaining stationary, a good representation of waves will be afforded, and the cloth will appear to advance; or if a strip of cloth be laid on a floor, repeated jerks at one end will produce a similar illusion.

It is only the *form* of the wave, and not the water which composes it, which has an onward motion. Let the dark line in *Fig.* 175 represent the surface of the

Fig. 175.



water. A is the crest of one of the waves, and being higher than the surface at B, it has a tendency to fall, and B to rise. But the momentum thus acquired carries these points so far that they interchange levels. The same change takes place with the other waves, and the dotted line shows the newly-formed surface as the water thus sinks in one place and rises in another. The same process is again repeated, and each wave thus advances further on, and the progressive motion is continually kept up.

BREADTH AND VELOCITY OF WAVES.

Each wave contains at any one moment particles in all possible stages of their oscillation; some rising and some falling; some at the top and some at the bottom; and the distance from any row of particles to the next row that is in precisely the same stage of oscilla-

tion, is called *breadth* of the wave, that is, the distance from crest to crest or from hollow to hollow.

There is a striking similarity between the rising and falling of waves and the vibrations of a pendulum, and it is a very interesting and remarkable fact that a wave always travels its own breadth in precisely the same time that a pendulum whose length is equal to that breadth performs one vibration. Thus, a pendulum $39\frac{1}{8}$ inches long beats once in each second, and a wave whose breadth is $39\frac{1}{8}$ inches travels that breadth in one second. The length of a pendulum must be increased as the square of the time for its vibrations; that is, to beat but once in two seconds, it must be four times as long as for one second; to beat once in three seconds, it must be nine times as long, and so on. In the same way, waves which travel their breadth in two seconds are four times as wide as those traveling their breadth in one second; and thus their breadth, and consequently their speed, increases as the square of the time. Large waves, therefore, roll onward with far greater velocity than small ones. If only thirty-nine inches wide, they move about two and a quarter miles an hour, and pass once each second; if

13	feet	wide,	they	move	$4\frac{1}{2}$	miles	an hour, passing once in 2 seconds.
52	do.	do.	9	do.	do.	4	do.
209	do.	do.	18	do.	do.	8	do.
836	do.	do.	36	do.	do.	16	do.

Although the water itself does not advance where there is much depth, yet when it reaches a shore or beach, the hard and shallow bottom prevents it from falling or subsiding, and it then rolls onward with a real progressive motion by the momentum it has ac-

quired, and breaks into foam and lashes the earth and rocks. The sea-billows are sometimes twenty-five feet in elevation,* and when these advance upon a stranded ship on a lee shore, with the speed of a locomotive, their effects are in the highest degree appalling, and iron bolts are snapped and massive timbers crushed beneath their violence.

PREVENTING THE INROAD OF WAVES.

To prevent the inroads of lake waves upon land, the remedies must vary with circumstances. The difficulty would be small if the water always stood at the same height. The greatest mischief is usually done when they *rise over* the beach of sand and gravel which they have beaten for centuries. Wooden bulwarks soon decay. Where loose stone can be had in large quantities they may be cheapest, but they are not unfrequently placed too near low-water mark to protect the banks. Substances which offer a gradual impediment to the waves are often quite effectual, though not formidable in themselves. It is curious to observe how so slender a plant as the bulrush, growing in water several feet deep, will destroy the force of waves. If it grew only near the shore, where the water has progressive motion, it would soon be dashed in heaps on the beach. Parallel hedgerows of the osier willow, protected by a wooden barrier until well grown and established, would in many cases prove efficient.

Stones and timber bulwarks are often made needlessly liable to injury by being built nearly perpen-

* No authentic measurement gives the perpendicular height of waves more than twenty-five feet.

dicular, and the waves break suddenly and with full force, like the blows of a sledge against them. A better form is shown in *Fig.* 176, where a slope is first presented to weaken their force without imposing a full resistance, and their strength is gradually spent as they rise in a curve. A more gradual slope than the figure represents would be still better. It is on this principle that the stability of the world-renowned Eddystone light-house depends. The base spreads out in every direction, like the trunk of a tree at the roots; and although the spray is sometimes dashed over its lofty summit by the violence of the storm, it has stood unshaken on its rocky base far out in the sea, against the billows and tempests, for nearly a century.

Fig. 176.

An instance occurred many years ago in England, where the superiority of knowledge over power and capital without it was strongly exemplified. The sea was making enormous breaches on the Norfolk and Suffolk coast, and inundated thousands of acres. The government commissioners endeavored to keep it out by strong walls of masonry and breakwaters of timber, built at great expense; but they were swept away by the fury of the billows as fast as they were erected. A skillful engineer visited the place, and with much difficulty persuaded them to adopt his simple plan. Observing the slope of the beach on a neighboring shore, he directed that successive rows of fagots or brush be deposited for retaining the sand, which was carted from the hills, forming an embankment with a

slope similar to that of the natural beach. Up this slope the waves rolled, and became gradually spent as they ascended, till they entirely died away. The breach was effectually stopped, and this simple structure has ever since resisted the most violent storms of the German Ocean.

SECTION V.

CONTENTS OF CISTERNS.

CONNECTED with the subject of hydraulics is the collection and security of water falling upon roofs, in all cases where a deficiency is felt by farmers in the drought of summer. The amount which falls upon most farm-buildings is sufficient to furnish a plentiful supply to all the domestic animals of the farm when other supplies fail, if cisterns large enough to hold it were only provided. Generally speaking, none at all are connected with barns and out-buildings, and even when they are furnished, they are usually so small as to allow four fifths of the water to waste.

If all the rain that descends in the Northern States of the Union should remain upon the surface without sinking in or running off, it would form each year a depth of about three feet. Every inch that falls upon a roof yields two barrels for each space ten feet square, and seventy-two barrels a year are yielded by three feet of rain. A barn thirty by forty feet supplies annually from its roof 864 barrels, or enough for more than two barrels a day for every day in the year. Many farmers have in all five times this amount of roof, or enough for twelve barrels a day yearly. If, however,

this water was collected, and kept for the dry season only, twenty or thirty barrels daily might be used.

In order to prevent a waste of water on the one hand, and to avoid the unnecessary expense of too large cisterns, their contents should be determined beforehand by calculation.

RULE FOR DETERMINING THE CONTENTS.

A simple rule to determine the contents of a cistern, circular in form, and of equal size at top and bottom, is the following: Find the depth and diameter in inches; square the diameter, and multiply the square by the decimal .0034, which will find the quantity in gallons* for one inch in depth. Multiply this by the depth, and divide by $31\frac{1}{2}$, and the result will be the number of barrels the cistern will hold.

For each foot in depth, the number of barrels answering to the different diameters are,

For 5 feet diameter	.....	4.66	barrels.
6 "	.....	6.71	"
7 "	.....	9.13	"
8 "	.....	11.93	"
9 "	.....	15.10	"
10 "	.....	18.65	"

By the rule above given, the contents of barn-yard cisterns and manure tanks may be easily calculated for any size whatever.

* This is the standard gallon of 231 cubic inches. The gallon of the State of New York contains 221.184 cubic inches, or 6 pounds at its maximum density.

DETERMINING THEIR SIZE.

The size of cisterns should vary according to their intended use. If they are to furnish a daily supply of water, they need not be so large as for keeping supplies for summer only. The average depth of rain which falls in this latitude, although varying considerably with season and locality, rarely exceeds seven inches for two months. The size of the cistern, therefore, in daily use, need never exceed that of a body of water on the whole roof of the building seven inches deep. To ascertain the amount of this, multiply the length by the breadth of the building, reduce this to inches, and divide the product by 231, and the quotient will be gallons for each inch of depth. Multiplying by 7 will give the full amount for two months' rain falling upon the roof. Divide by $31\frac{1}{2}$, the quotient will be barrels. This will be about fourteen barrels for every surface of roof ten feet square when measured horizontally. Therefore, a cistern for a barn 30 by 40 feet should hold 168 barrels; that is, as large as one ten feet in diameter and nine feet deep. Such a cistern would supply, with only thirty inches of rain yearly, no less than 630 barrels, or nearly two a day.

Cisterns intended only for drawing from in times of drought, to hold all the water that may fall, should be about three times the preceding capacity.

PART III.

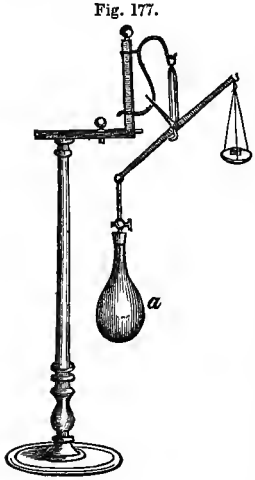
PNEUMATICS.

CHAPTER I.

PRESSURE OF AIR.

PNEUMATICS treats of the mechanical properties of the air.

Fig. 177.



Balance for Weighing Air.

The actual weight of the air may be correctly found by weighing a strong glass vessel furnished with a stop-cock, *a* (*Figure* 177), after the air has been withdrawn from it by means of an air-pump. Let it be accurately balanced by weights in the opposite scale; then turn the stop-cock and admit the air, and it will immediately descend, as shown in the figure. The weight of the admitted air may be ascertained by adding weights till it is again balanced.

HEIGHT AND WEIGHT OF THE ATMOSPHERE.

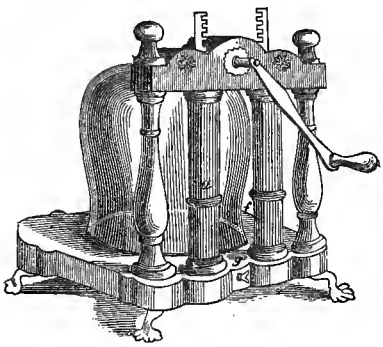
The atmosphere which covers the earth extends upward to a height of about fifty or sixty miles. At the

surface of the earth the air is about eight hundred times lighter than the water, and the higher we ascend, the rarer or lighter it becomes, from the diminished pressure of its weight above. At seven miles high, it is four times lighter than at the surface; at twenty-one miles, it is sixty-four times lighter; and at fifty miles, about twenty thousand times lighter. At this height it ceases to refract the rays of the sun so as to render it visible at the earth's surface; but if it decreases at the same rate upward, at a hundred miles high it must be nearly a thousand million times rarer than at the earth.

If the atmosphere were uniformly of the same density, with its present weight, it would reach only five miles high. Although so much lighter than water, yet, from its great height, it presses upon the surface of the earth as heavily as a depth of thirty-three feet of water. This is nearly equal to fifteen pounds on every square inch, or more than two thousand pounds to the square foot. This enormous weight would instantly crush us, did not air, like liquids, press in every direction, so that the upward exactly counterbalances the downward pressure, and the air within the body counteracts that without.

The weight of the atmosphere is strikingly shown by means of an air-pump, which pumps the air from a glass vessel, placed mouth downward upon the brass plate of the machine (*Fig.* 178). When the air is pumped out, and the upward or counterbalancing air removed, so heavy is the load upon the glass vessel, that a strong man could scarcely remove it from the plate, although it be no larger than a small tumbler.

Fig. 178.



Air-pump.

A glass jar with a mouth six inches across would need a force equal to nearly four hundred pounds to displace it. If there be a glass vessel open at both ends, the hand placed on the top may be so firmly held by the pressure that it can not be removed until the air is again admitted below (*Fig.* 179). If a thin plate of glass be placed on the top of this open vessel, on pumping out the air, the weight will suddenly crush it with a noise like the report of a gun.

Fig. 179.

The Hand fastened by Air.

Some interesting instances occur in nature of the use of atmospheric pressure. Flies walk on glass by means of the pressure against the outside of their feet, the air having been forced out beneath. In a similar way, some kinds of fishes cling to the sides of rocks under water, so as not to be swept off by the current. Dr. Shaw threw a fish of this kind into a pail of water, and it fixed itself so firmly to the bottom, that, by taking hold of the tail, he lifted up the pail, water and all.

It is the pressure of the atmosphere upon water that drives it up the barrel of a pump as soon as the air is pumped out from the inside. Hence the reason that pumps can never be made to draw water more than

thirty-three feet below the piston, a height corresponding to the weight of the atmosphere.

THE BAROMETER.

On the same principle the *Barometer* is made. It consists of a glass tube, nearly three feet long, open at one end, and which is first filled with mercury, a liquid nearly fourteen times heavier than water. The open end is then placed downward in a cup of mercury. The weight of the mercury in the tube causes it to descend until the pressure of the atmosphere on the mercury in the cup preserves an equilibrium, which takes place when the column in the tube has fallen to about two feet and a half high, the upper part of the tube being left a perfect vacuum, as no air can enter (*Fig.* 180). Now, as the height of the column of mercury depends alone upon the weight of the atmosphere, then, whenever the air becomes lighter or heavier, as it constantly does during the changes of the weather, the rising or falling of the column indicates these changes; and, what is very important, it shows the approaching changes of the weather several hours before they actually take place. Hence it becomes a valuable assistant in foretelling the weather. When the mercury falls, showing that the atmosphere is becoming lighter, it indicates the approach of storms or rain; when it rises, a settled or fair sky follows. These are often foreshown before there is any change in the appearance of the sky. For this reason the barometer is sometimes called a *weather-glass.* It is of the greatest value to navigators at sea. Long voyages

Fig. 180.

Barometer.

which formerly required a year have been made in eight months by means of the assistance afforded by the barometer, admitting a full spread of canvas by night as well as by day, from the certainty of its predictions. On land its indications are not so certain, and at some places less so than at others. Sometimes, and more commonly during autumn and winter, the sinking of the mercury is followed only by wind instead of rain. There is, however, no doubt that its use would be of much advantage in large farming establishments, more especially during the precarious seasons of haying and harvesting.

The barometer is an instrument of great value in determining with little labor, and with considerable accuracy, the heights of mountains, hills, and the leading points of an extensive district of country. In rising above the level of the sea, the weight of the air above us becomes less; that is, the pressure of the air upon the barometer decreases, and the column of mercury gradually falls as we ascend. To determine, therefore, the height of a mountain, we have only to place one barometer at its foot while another stands at the top, and then, by observing the difference in the height of the mercury, we are enabled to calculate the height of the mountain. The following table shows how much the barometer falls at different altitudes, thirty inches being taken for the sea-level:*

* The mercury rarely stands as high as 30 inches at the level of the sea, the mean height being about 29.5 inches. But this does not affect the measurement of heights, which is determined, not by the actual height, but by the *difference* in heights.

At 1000 feet	above	the	sea,	the	column	falls to	28.91 inches.
2000	"	"	"	"	"	27.86	"
3000	"	"	"	"	"	26.85	"
4000	"	"	"	"	"	25.87	"
5000	"	"	"	"	"	24.93	"
1 mile		"	"	"	"	24.67	"
2 "		"	"	"	"	20.29	"
3 "		"	"	"	"	16.68	"
4 "		"	"	"	"	13.72	"
5 "		"	"	"	"	11.28	"
10 "		"	"	"	"	4.24	"
15 "		"	"	"	"	1.60	"
20 "		"	"	"	"	0.95	"

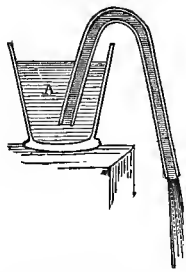
At the level of the sea, the barometer falls about one hundredth of an inch for a rise of nine feet, or a little more than the tenth of an inch for a rise of one hundred feet. At a height of one mile it requires about eleven feet rise to sink the mercury a hundredth of an inch.

In selecting land in mountainous districts of the country, where degrees of frost increase with increased altitudes, and where the height of one portion above another has an important relation to the cost of drawing loads up and down hill, the barometer might become of much practical value.

THE SYPHON.

The *syphon* operates on a principle quite similar to that of the pump; but, instead of pumping out the air of the tube through which the water rises, a vacuum is created by the weight of a column of water, in the following way: *Fig.* 181 represents a syphon, which is nothing more than a tube bent in the form of a letter U inverted. Now, if this be filled throughout with

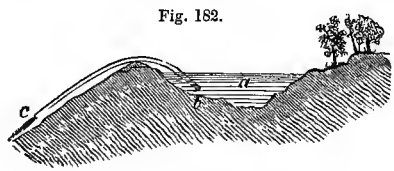
Fig. 181.



water, and then placed with the shorter arm in the vessel of water, A, the weight of the column of water in the longer arm, which is outside, will overbalance the weight of the other column, and will therefore run out in a stream. This tends to cause a vacuum in the tube, which is instantly filled by the water rushing up the shorter arm, being driven up by the pressure of the atmosphere. A stream will consequently continue running through the syphon until the vessel is drained.

The syphon may sometimes be very usefully employed in emptying pools or ponds of water on high ground, without the trouble of cutting a ditch for this purpose. For instance, let *a* (*Fig.* 182) represent a

Fig. 182.



body of water which it is desirable to drain off; by placing the lead tube, *b c*, so that the arm, *c*, may be lowest, and applying a pump at this arm to withdraw the air and fill the syphon with water, it will commence running, and continue till the water has all been drawn off. Difficulties, however, sometimes occur. If the tube is small and very long, and the descent is trifling, the friction of the water in the tube may prevent success. Water usually gives out small quantities of air, which collects in the higher part of the sy-

phon, and after a while fills it, causing the stream to cease running; but syphons for this purpose, when only a few rods in length, with several feet descent, are usually found to succeed well. If the discharging orifice is several times smaller than the tube, it is frequently of material use, by causing a slow and steady current through the syphon.

CHAPTER II.

MOTION OF AIR.

SECTION I.

WINDS.

WIND is air in motion. Its force depends on its speed. When its motion is slow, it constitutes the soft, gentle breeze. As the velocity increases, the force becomes greater, and the strong gale sweeps round the arms of the wind-mill with the strength of many horses, and huge ships are driven swiftly through the waves by its pressure. By a still greater velocity of the air, its power becomes more irresistible, and solid buildings totter, and forest trees are torn up by the roots in the track of the tornado.

The force of wind increases directly as the square of the velocity. Thus a wind blowing ten miles an hour exerts a pressure four times as great as at five miles an hour, and twenty-five times as great as at two miles an hour. The following table exhibits the force of wind at different degrees of velocity:

Miles an hour.	Pressure in lbs. on a square foot.	Description.
1	.005	Hardly perceptible.
2	.020	Just perceptible.
3	.045	
4	.080	Light breeze.
5	.125	
6	.180	Gentle, pleasant wind.
7	.320	

Miles an hour.	Pressure in lbs. on a square foot.	Description.
10	.500	Pleasant, brisk wind.
15	1.125	
20	2.000	Very brisk.
25	3.125	
30	4.500	Strong, high wind.
35	6.125	
40	8.000	Very high.
45	10.125	
50	12.500	Storm or tempest.
60	18.000	Great storm.
80	32.000	Hurricane.
100	50.000	Tornado, tearing up trees, and sweeping off buildings.

These forces may be observed at a time when the air is still, by a forward motion equal to that of the wind. Thus walking moderately gives the faint breeze against the face; riding in a wagon at six miles an hour causes the sensation of a pleasant wind; the deck of a steamboat at fifteen miles produces a brisk blow; while an open rail-car at forty miles an hour occasions a sweep of the air nearly resembling a tempest.

The preceding table will enable any one to calculate with considerable accuracy the amount of draught which a horse must constantly overcome in traveling with a covered carriage against the wind, adding, of course, the speed of the horse to that of the wind. For example, suppose a horse with a covered carriage is driven against what we term "a very brisk wind," blowing 24 miles an hour, and pressing 3 lbs. on the square foot. The carriage top offers a resisting surface four feet square, or with sixteen square feet. Three times sixteen, or 48 lbs., are consequently required to be overcome with every onward step of the horse.

Now we have already seen, when treating of "application of labor," that a horse traveling three miles an hour for eight hours, will overcome only 83 lbs. with ordinary working, which is not double the resistance of the wind. Hence we perceive that more than half the horse's strength is lost by driving against such a current. At six miles an hour, all his strength, without over-driving, would be expended in overcoming the force of the wind, and the power required for moving the carriage would be so much excessive labor. For simplifying the operation, the increased motion of the wind occasioned by driving against it has not been taken into account.

Even with a small pressure, the loss in power is considerable for an entire day. When, for example, the air is perfectly still, traveling six miles an hour will cause a constant resistance of 3 lbs. on the carriage, or one fourteenth of the power exerted for a full day's work. The same speed against a "gentle wind" of six miles an hour, added, would increase the resistance fourfold, or equal to 12 lbs.; more than one fourth of the horse's strength at six miles an hour through the day.

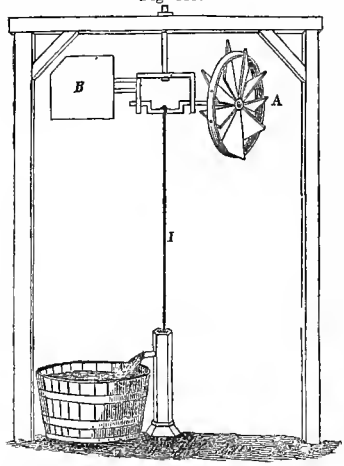
WIND-MILLS.

The power possessed by the sails of a wind-mill may be nearly ascertained in the same way, the area of the sails being known, and first deducting their average velocity.

The force of wind may be usefully applied by almost every farmer, as it is a universal agent, possessing in this respect great advantages over water-power, of which very few farms enjoy the privilege.

Wind may be applied to various purposes, such as sawing wood by the aid of a circular saw, turning grindstones, and particularly in pumping water. One of the best contrivances for pumping is represented by *Fig.* 183, where A is the circular wind-mill, with a number of sails set obliquely to the direction of the wind, and always kept facing it by means of the vane, B. The crank of the wind-mill, during its revolutions, works the pump-rod, I, and raises the water from the well beneath. In whatever direction the wind may blow, the pump will continue working. The pump-rod, to work steadily, must be immediately under the iron rod on which the vane turns. If the diameter of the wind-mill is four feet, it will set the pump in motion even with a light breeze, and with a brisk wind will perform the labor of a man. Such a machine will pump the water needed by a large herd of cattle, and it may be placed on the top of a barn, with a covering, to which may be given the architectural effect of a tower or cupola, as shown in *Fig.* 184, opposite.

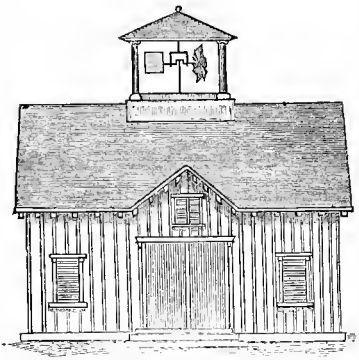
Fig. 183.



Wind-mill for pumping water on farms: A, wind-mill; B, vane; I, pump-rod.

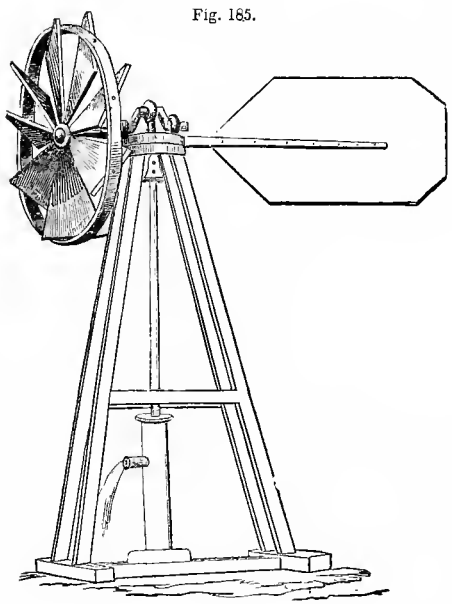
A more compact machine, but of more complex construction, is shown in *Fig.* 185, opposite, where the up-

Fig. 184.



Barn surmounted with wind-mill for pumping water, cutting straw, &c.

Fig. 185.



per circle moves around with the wheel and vane on the fixed lower circle, to which it is strongly secured so as to admit of turning freely. In other respects it is similar to the preceding.

In all wind-mills, it is important that the sails should have the right degree of inclination to the direction of the wind. If they were to remain motionless, the angle would be different from that in practice. They should more nearly *face* the wind; and as the ends of the sails sweep round through a greater distance and faster, they should present a flatter surface than the parts nearer the centre. The sails should, therefore, have a twist given them, so that the parts nearest the centre may form an angle of about 68 degrees with the wind, the middle about 72 degrees, and the tips about 83 degrees.

In order to produce the greatest effect, it is necessary to give the sails a proper velocity as compared with the velocity of the wind. If they were entirely unloaded, the extremities would move faster than the wind, in consequence of its action on the other parts. The most useful effect is produced when the ends move about as fast as the wind, or about two thirds the velocity of the average surface.

The most useful wind is one that moves at the rate of eight to twenty miles per hour, or with an average pressure of about one pound on a square foot. In large wind-mills, the sails must be lessened when the wind is stronger than this, to prevent the arms from being broken; and if much stronger, it is unsafe to spread any, or to run them.

CAUSES OF WIND.

The motion of air in producing wind is explained by the action of heat, *although there are many irregular currents whose cause is not well understood.* The simplest illustration of the effect of heat in causing currents is furnished by the land and sea breezes in warm latitudes. The rays of the sun during the day heat the surface of the land, and the air in contact with it also becoming heated, and thus rendered lighter, flows upward; the air from the sea rushes in to fill the vacancy and causes the sea-breeze. During the night, the radiation of heat from the land into the clear sky above cools the surface to a lower temperature than that of the sea; consequently the air in contact with the sea becomes heated the most, and rising, causes the wind from the land to flow in and supply the place. Trade-winds are caused in a similar way, but on a much larger scale, by the greater heat of the earth at the equator, which produces currents from colder latitudes. These currents assume a westerly tendency, in consequence of the velocity of the earth being the greatest at the equator, and which, outstripping the momentum which the winds have acquired in other latitudes, tends to throw them behind, or in a westerly direction.

SECTION II.

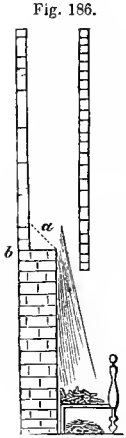
CHIMNEY CURRENTS.

Chimney Currents are produced by the heat of the fire rarefying the air, which rises and carries the smoke with it. The taller the chimney is, the longer will be

the column of rarefied air tending upward, and, as a consequence, the stronger will be the draught. In kindling a fire in a cold chimney, there is very little current till this column becomes heated. The upward motion of heated currents is governed by laws similar to the downward motion of water in tubes, where the velocity is increased with the height of the head. But as air is more than eight hundred times lighter than water, slight causes will affect its currents, which would have no sensible influence on the motion of liquids. For instance, a strong wind striking the top of a chimney may send the smoke downward into the room; and a current can not be induced through a horizontal pipe without connecting with it an upright pipe of considerable height.

CONSTRUCTION OF CHIMNEYS.

Fig. 186.

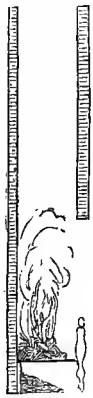


A well-built Chimney.

In constructing chimneys to produce a strong draught, the throat immediately above the fire, which should have a breadth equal to that of the fire-place, should be contracted to a width of about four inches, so that the column of rising air above may draw the air up through the throat with increased velocity, as shown in *Fig.* 186. This arrangement also allows the fire to be built so as to throw the heat more fully out into the room. By leaving the shoulder at *b* square or flat, it will tend to arrest any reversed or downward current in a better manner than if built sloping, as shown by the dotted line at *a*, which would act

like a funnel, and throw the smoke into the room. The throat should be about as high as the extreme tip of the flame; if much higher, the chimney will not draw so well, and if lower, too much of the heat will be lost. *Fig.* 187 shows a fire-place without a contracted throat, the current of which is comparatively feeble. Many chimneys draw badly by being made too large for the fire to heat sufficiently the column of air they contain.

Fig. 187.



A badly-built Chimney.

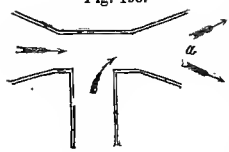
CHIMNEY-CAPS.

When wind sweeps over the roof of a high part of the building, or over a hill, it often strikes the top of chimneys below, and drives the smoke downward. This may be often prevented by placing a cap over the chimney, like that represented by *Fig.* 188, which is supported at its corners, the smoke passing out at the four sides just under the eaves of this cap. But it sometimes happens that there is a confusion of currents and eddies at the top of the chimney, over which this cap has no influence. In this case, the cap represented by *Fig.* 189 furnishes a perfect remedy, and is, indeed, perfect in its operation under any circumstances whatever, for the chimney surmounted by it will always draw when there is wind from any quarter, with or without any fire. It has effected a perfect cure in some chimneys which before were exceedingly troublesome, and were

Fig. 188.

Fig. 189.

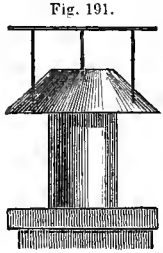
Fig. 190.



regarded as incurable. *Fig.* 190 is intended to show the mode of its operation, the wind, as shown by the arrows, being deflected for a considerable distance on the lee side, so as to form a vacancy at *a*, which the wind from the other end and from the chimney both rush in to supply. Being fixed on without turning in the chimney, it is both simpler and less noisy than any caps furnished with a vane.

Emerson's Chimney-cap, lately invented, is different in construction, but quite similar in principle to the preceding. It is shown by *Fig.* 191. A sheet-iron pipe is set in the top of the chimney, furnished with the conical rim, and a plate or fender on the top which excludes the rain. Between the plate and rim is a space quite similar in form or section to that represented by *Fig.* 190.

Fig. 191.



In exposed situations, chimneys are found to draw more uniformly by contracting the top about a third less than the rest of the flue. The current at the moment of escape is swifter than below, and less acted upon by any downward check from the

Fig. 192.

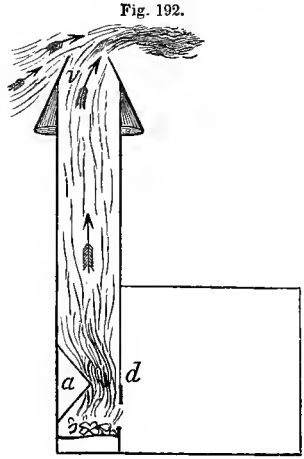
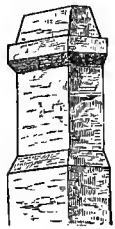


Fig. 193.

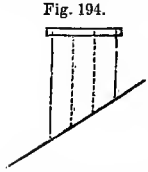


wind, at the same time that the surface is smaller on which the wind can strike the current, as shown in *Fig.* 192. A chimney of this character may be very easily made by contracting the tiers of brick, thus giving to it an ornamental appearance, as seen in *Fig.* 193.*

* Where different fires communicate with the same chimney, separate flues should be built for each fire, and kept separate in the same chimney-stack, carried up independently of each other. But even with this precaution, smoky rooms will not be avoided, unless the termination of the chimney is of the right form, of which the following illustration is given in Allen's *Rural Architecture:*

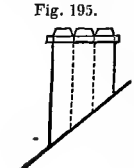
"Fifteen years ago we purchased and removed into a most substantial and well-built stone house, the chimneys of which were constructed with open fireplaces, and the flues carried up separately to the top, where they all met upon the same level surface, as chimneys in past

Fig. 194.



times usually were built, thus. Every fireplace in the house (and some of them had stoves in) smoked intolerably; so much so, that when the wind was in some quarters, the fires had to be put out in every room but the kitchen, which, as good luck would have it, smoked less—although it did smoke there—than the others. After balancing the matter in our own mind some time whether we would pull down and rebuild the chimneys altogether, or attempt an alteration—as we had given but little thought to the subject of chimney draft, and to try an experiment was the cheapest—we set to work a bricklayer, who, under our direction, simply built over each discharge of the several flues a separate

Fig. 195.



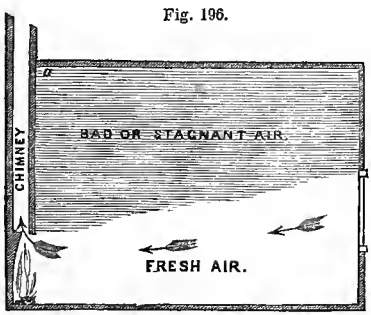
top of fifteen inches high, in this wise: the remedy was perfect. We have had no smoke in the house since, blow the wind as it may, on any and on all occasions. The chimneys *can't* smoke; and the whole expense for four chimneys, with their twelve flues, was not twenty dollars! The remedy was in giving each outlet a *distinct* current of air all around, and on every side of it."

VENTILATION.

Impure air may be breathed for a short time without any serious detriment, but to live in it and respire it for years can not fail to produce permanent injury to the health. During the heat of summer, open doors and windows will usually furnish plenty of fresh air, as long as this season lasts, which in the Northern States is not one half of the year. During the rest of the time rooms are heated with close stoves, and unless special care is taken to secure fresh air, pale or sickly inmates will be the most likely results.

Even with a common open fire-place, which causes more circulation of the air in a room than stoves, the ventilation is very imperfect. The following figure (*Fig.* 196) represents the fresh air as passing in from

Fig. 196.



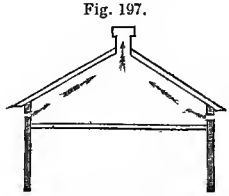
A badly-ventilated Room.

an open window opposite the fire, producing a direct current from the window to the chimney, and leaving all the upper portion of the room filled with bad air, unaffected by the change. The cold air can not rise, nor the hot air descend. This difficulty may be easily

removed by placing a register (which may be closed or opened at pleasure) at *a*, in the upper corner, so that the confined air may escape into the chimney. Without this provision, it is nearly impossible to preserve the air in proper condition for breathing, for the upper part, being warmest and lightest, remains unchanged at the top. In rooms heated by stoves, registers for escape of the foul air are still more important, where the thermometer frequently indicates twenty degrees difference in the heat above and at the floor, the lower stratum of air resting like a cold lake about the feet, while the head is heated unduly.

When the draught of the chimney-fire is not strong, the smoke may, however, escape through the ventilating register into the room. To avoid this difficulty, it is best to provide separate air-flues in the walls when the house is built, for effecting perfect ventilation. In rooms strongly heated by fires, the fresh air should be admitted near the ceiling, producing descending currents, and effecting a complete circulation in the air of the room. But in sleeping apartments and in closets, not heated artificially, and where the descending currents will not take place, the fresh air should be admitted through a register or small rolling blind near the floor, and discharged near the ceiling into an air-flue.

Fig. 197.

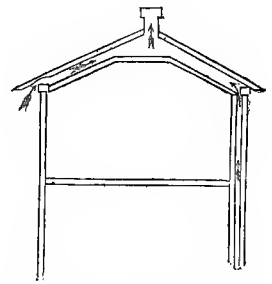


Mode of Ventilating Garrets.

The excessive warmth of garrets in mid-summer may be avoided by placing a ventilator at the highest part, and admitting air at windows or openings near the eaves (*Fig.* 197), thus sweeping all the hot air out by

the current produced; or, the oppressive heat of half-story bedrooms may be similarly avoided, by creating a current of air between the roof and the plastering (*Fig.* 198). Two modes may be adopted, as represented on each side of the figure.

Fig. 198.



Mode of Ventilating half-story Bedrooms.

PART IV.

HEAT.

CHAPTER I.

CONDUCTION OF HEAT.

SECTION I.

CONDUCTING POWER OF BODIES.

When any substance or body has become heated, it loses its heat in two different ways, by *conduction* and by *radiation*. When conducted, heat passes off slowly or gradually through bodies, as when a pin is held by the hand in a candle, the heat advancing from one end to the other till it burns the fingers; or, when an iron poker is thrust into the fire, the heat gradually passes through it till the whole becomes hot. Iron and brass are, therefore, said to be good conductors of heat. The end of a pipe-stem may, however, be heated to redness, and a wooden rod may be set on fire, without even warming the other extremity, because the heat is very slowly conducted through them. Wood and burned clay are, therefore, *poor* conductors.

The comparative conducting power of different substances may be shown by placing short rods of each with one of their ends in a vessel of hot sand, the others to be tipped with wax. The different periods of time required to melt the wax indicate the relative

conducting powers. It will speedily melt on the copper rod; soon after, on the rod of iron; glass will require longer time; stone or eathenware still longer; while on a rod of wood it will scarcely melt at all. These rods should be laid horizontally, that the hot air rising from the sand may not affect the wax. The conducting powers may be judged of likewise, with considerable accuracy in cold weather, by merely placing the hand upon the different substances. The best conductors will feel coldest, because they withdraw the heat most rapidly from the hand. Iron will feel colder than stone; stone colder than brick; wood still less so; and feathers and down least of all, although the real temperature of all may be precisely the same.

UTILITY OF THIS PRINCIPLE.

A knowledge of this property is often very useful. For instance, it is found that hard and compact kinds of wood, as beach, maple, and ebony, conduct heat nearly twice as rapidly as light and porous sorts like pine and basswood. Hence doors and partitions made of light wood make a warmer house than those that are more heavy and compact. Pine or basswood would, in this respect, be better than oak or ash.

Porous substances of all kinds are the poorest conductors; saw-dust, for example, being much less so than the wood that produced it. For this reason, saw-dust has been used as a coating around the boilers of locomotives to keep in the heat, and for the walls of ice-houses to exclude it. Sand, filled in between the double walls of a dwelling, renders it much warmer in winter and cooler in summer than if *sandstone* were

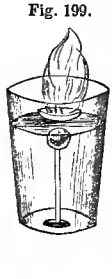
made to fill the same space. Ashes, being more porous, are found to be still better. Tan, which is similar to saw-dust, is well adapted to filling in the walls of stables and poultry-houses, where more than usual warmth in winter is required. Confined air is a very poor conductor of heat; hence the advantage of double walls and double windows, provided there are no crevices for the escape of the confined air. This principle has been lately applied in the manufacture of *hollow brick* for building the walls of dwellings.

The light and porous nature of snow renders it eminently serviceable as a clothing to the earth in the depth of winter, preventing the escape of the heat from below, and protecting the roots of plants from injury or destruction. Hence the very severity of the cold of the Northern regions, by producing an abundance of those beautiful feathery crystals which form snow, becomes the means of protecting from its own effects the tender herbage buried beneath this ample shelter.

CONDUCTING POWER OF LIQUIDS.

Liquids are found to conduct heat very slowly, and they were for a long time considered perfect non-conductors. Some interesting experiments have been performed in illustration of this property. A large glass jar may be filled with water (*Fig.* 199), in which may be fixed an air thermometer, which is always very quickly sensitive to small quantities of heat. A shallow cup of ether, floating just above the bulb, may be set on fire, and will continue to burn for some time before any effect can be seen upon

Fig. 199.



the thermometer. The upper surface of a vessel of water has been made to boil a long time, with a piece of unmelted ice at the bottom. Liquids are found, however, to possess a conducting power in a very slight degree.

When a vessel of water is heated in the ordinary way over a fire, the heat is carried through it merely by the motion of its particles. The lower portion becomes warm and expands; it immediately rises to the surface, and colder portions sink down and take its place, to ascend in their turn. In this way, a constant circulation is kept up among the particles. These rising and descending currents are shown by the arrows in *Fig.* 200. This result may be easily shown by filling a flask with water into which a quantity of sawdust from some green hard wood has been thrown, which is about as heavy as water. It will traverse the vessel in a manner precisely like that shown in the figure.

Fig. 200.

These results show the importance of applying heat directly to the bottom of all vessels in which water is intended to be heated. A considerable loss of heat often occurs when the flame is made to strike against the sides only of badly-arranged boilers.

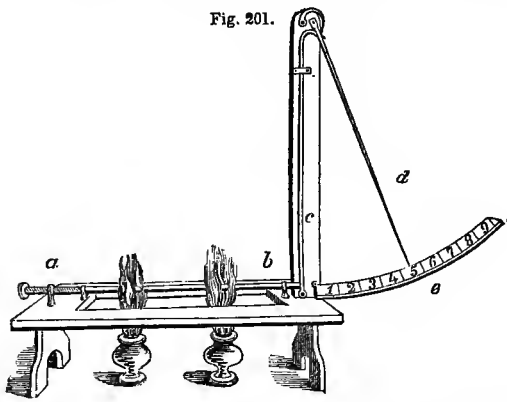
SECTION II.

EXPANSION BY HEAT.

An important effect of heat is the expansion of bodies. Among many ways to show it, an iron rod may be so fitted that it will just enter a hole made for the

purpose in a piece of sheet-iron. If the rod be now heated in the fire, it expands and becomes larger, and can not be thrust into the hole. The expansion may be more visibly shown and accurately measured by means of an instrument called the *Pyrometer* (*Fig.* 201). The rod *a b*, secured to its place by a screw at

Fig. 201.



a, presses against the lever *c*, and this against the lever, or index, *d*, both of which multiply the motion, and render the expansion very obvious to the eye when the rod is heated by the lamps. If the rod should expand one fiftieth of an inch, and each lever multiplies twenty times, then the index (or second lever) will move along the scale eight inches; for 20 times 20 are 400, and 400 50ths of an inch are 8 inches.

Many cases showing the expansion of heated bodies occur in ordinary practice. One is afforded by the manner in which the parts of carriage wheels are bound together. The tire is made a little smaller than the wooden part of the wheel; it is then heated till, by

expanding, it becomes large enough to be put on, when it is suddenly cooled with water, and by its powerful contraction binds every part of the wheel together with great force. Hogsheads are firmly hooped with iron bands in the same way, with more force than could be ever given by driving on with blows of the mallet.

This principle was very ingeniously applied in drawing together two expanding brick walls of a large building in Paris, which threatened to burst and fall. Holes were drilled in the opposite walls, through which strong iron bars across the building projected, and circular plates of iron were screwed on these projecting ends. The bars were then heated, which increased their length; the plates were then screwed closely against the walls. On cooling, they contracted, and drew the walls nearer together. The process was repeated on alternating bars, until the walls were restored to their perpendicular positions.

All tools, where the wooden handles enter iron sockets, will hold more firmly if the metal is heated before inserting the wood.

The metallic parts of pumps sometimes become very difficult to unscrew, and a case has occurred where two strong men could not start the screws, until a bystander suggested that the outer piece be heated, keeping the inner cool, when a force of less than ten pounds quickly separated them. In other cases, where the large iron nuts have been thoughtlessly screwed, while warmed with the hands, on the cold metallic axles of wood-sawing machines in winter, they have contracted so that the force of two or three men has been insufficient to turn them.

The sudden expansion of bodies by heat sometimes causes accidents. Thick glass vessels, when unequally heated, expand unequally, and break. Heated plates of cast iron or cast kettles are very liable to be fractured by suddenly pouring cold water upon them. The same effect has been usefully applied in splitting the scattered rocks which encumber a farm, and which are too large to remove while entire. Fires are built upon them; the upper surface expands, while the lower remains cold, and large portions are successively separated in scales, and sometimes the whole rock is severed. The only care needed is to observe attentively and remove with an iron bar any parts which may have become loosened by the heat, and which would prevent the heat from passing to other portions. One man will thus attend to a large number of fires, and will split in pieces ten times as many rocks in a day as by drilling and blasting.

THE STEAM-ENGINE.

Fig. 202.

The *Steam-engine* owes its power to the enormous expansion of water at the moment it is converted into steam, which is about 1600 times its bulk when in the form of water. The principle on which the steam-engine acts may be understood by a very simple instrument represented in *Fig.* 202. A glass tube with a small bulb is furnished with a solid air-tight piston, capable of working up and down. The water in the bulb, *a*, is heated with a spirit-lamp or sand-bath; the rising

steam forces up the piston. Now immerse the bulb in cold water or snow, and the steam is condensed again into water, the tube is left vacant, and the pressure of the atmosphere forces down the piston. By thus alternately applying heat and cold, it is driven up and down like the piston of a steam-engine. The only difference is, the steam-engine is furnished with apparatus so that this application of heat and cold is performed by the machine itself. The bulb represents the boiler, and the tube the cylinder; but in the steam-engine the boiler is separate, and connected by a pipe with the cylinder; and instead of applying the cold water directly to the cylinder, it is thrown into another vessel called the condenser, connected with the cylinder.

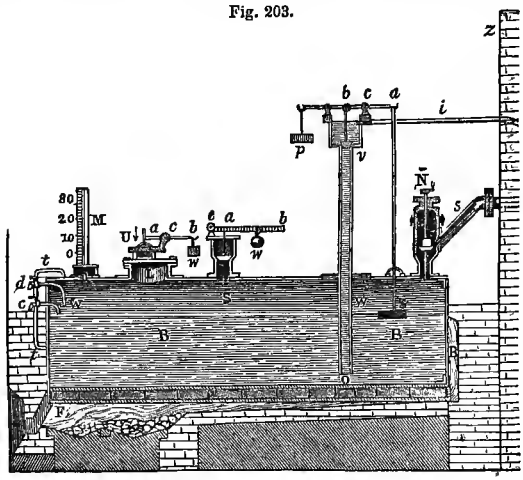
When Newcomen, who made the first rude regularly-working engine, began to use it for pumping water, he employed a boy to turn a stop-cock, connected with the condenser, every time the piston made a stroke. The boy, however, soon grew tired of this incessant labor, and endeavored to find some contrivance for relief. This he effected by attaching a rod from the piston or working-beam to the cock, which was turned by the machine itself at every stroke. This was the origin of the first self-acting engine.

The different parts of a common steam-engine may be understood from the following figures, one representing the boiler, and the other the working machinery.

The boiler, B (*Fig.* 203), contains water in the lower part and steam in the upper; F B is the fire; *v o* is the *feed-pipe;* *v*, a valve, closed by the lever, *b c a*, whenever the boiler is full enough, by means of the ris-

ing of the float, S, and opened whenever the float sinks from low water. M, *barometer gauge*, to show the

Fig. 203.

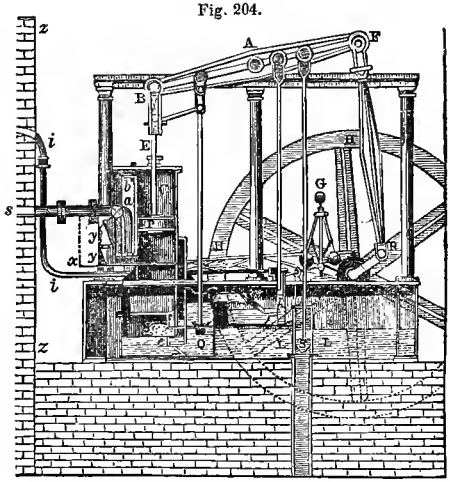


Boiler of Steam-engine.

pressure of the steam; *w*, weight on the lever, *e b*, for holding down the *safety-valve:* this lever being graduated like a steelyard, the force of the steam may be accurately weighed. U is a valve opening downward, to prevent the boiler being crushed by atmospheric pressure, by allowing the air to pass in whenever the steam happens to decline. Two tubes with stop-cocks, *c* and *d*, one just below the water-level and the other just above it, serve to show, by opening the cocks, whether the water is too high or too low.

The working part of the engine is represented in the figure on the following page (*Fig.* 204). The steam enters by the pipe, *s*, from the boiler on the other side of the brick wall, as shown in *Fig.* 203. The steam

Fig. 204.



Low-pressure Steam-engine.

passes through what is called a *four-way-cock*, *a*, first into the lower, then into the upper end of the cylinder, C, as the piston, P, moves up and down; this is regulated by the levers, *y y*. The piston-rod, E, is attached to the working-beam, B F, turning on the centre, A. The rod, F R, turns the fly-wheel, H H, and drives the mill, steam-boat, or machinery to be put in motion.

The *condenser*, *j*, shown directly under the cylinder, remains to be described. It is immersed in a cistern of cold water, and is connected by pipes to the upper and lower end of the cylinder. Through these pipes the steam passes out of the cylinder, first from one end and then from the other, and is condensed into water by a jet of cold water thrown into it by the *injection-cock*. When condensed, it is pumped out by the pump, O, into the *well* or reservoir, W, and then again into

the feed-pipe of the boiler. Warm water is thus constantly supplied to the boiler, and effects a great saving of fuel.

The supply of steam and the motion of the engine are regulated by the *governor*, G. When the motion is too fast, the two suspended balls, which revolve on a vertical or upright axis, and which hang loosely like pendulums, are thrown out from the axis, producing the movement of a rod which shuts the steam-valve. When the motion is too slow, the balls approach the axis and open the valve.

In *high-pressure* engines the steam is not condensed, but escapes into the open air at every stroke of the piston, which produces the loud, successive *puffs* of all engines of this kind.

The steam-engine, in its most perfect form, is a striking example of human ingenuity, and its qualities are thus described by Dr. Arnott: "It regulates with perfect accuracy and uniformity the number of its strokes in a given time, and records them as a clock does the beats of its pendulum. It regulates the quantity of steam; the briskness of the fire; the supply of water to the boiler; the supply of coals to the fire. It opens and shuts its valves with absolute precision as to time and manner; it oils its joints; it takes out any air accidentally entering parts which should be vacuous; and when any thing goes wrong which it can not of itself rectify, it warns its attendants by ringing a bell; yet, with all these qualities, and even when exerting a force of six hundred horses, it is obedient to the hand of a child. Its aliment is coal, wood, and other combustibles. It consumes none while idle. It

never tires, and wants no sleep. It is not subject to any malady when originally well made, and only refuses to work when worn out with age. It is equally active in all climates, and will do work of any kind: it is a water-pumper, a miner, a sailor, a cotton-spinner, a weaver, a blacksmith, a miller, a printer, and is indeed of all occupations; and a small engine in the character of a steam pony may be seen dragging after it, on an iron rail-way, a hundred tons of merchandise or a thousand persons with the speed of the wind."

Steam-engines have been much used on large farms in England for thrashing, grinding the feed of animals, cutting fodder, and for other purposes. They have been less used here, but may prove useful for large establishments, where the teams for ordinary tillage are insufficient for stationary labor.

More difficulty exists in their use for plowing, in consequence of the labor and expense of moving frequently so heavy a machine, and the still greater difficulty of using a locomotive power like that on rail-roads on the soft surfaces of farms.

EXCEPTION TO EXPANSION BY HEAT.

A striking exception to the general law of expansion by heat occurs in the freezing of water.* During its change to a solid state, it increases in bulk about one twelfth, and this expansion is accompanied with a great force. The bottoms of barrels are burst out, and cast-iron kettles are split asunder, when water is suffered wholly to freeze in them. Lead pipes filled with

* There are a very few other substances which expand on passing from a liquid to a solid state.

ice expand; but if it is often repeated, they are cracked into fissures. A strong brass globe, the cavity of which was only one inch in diameter, was used by the Florentine academicians for the purpose of trying the expansive force of freezing water, by which it was burst, although the force required was calculated to be equal to *fourteen tons*. Experiments were tried at Quebec, in one of which an iron plug, nearly three pounds in weight, was thrown from a bomb-shell to the distance of 415 feet; and in another, the shell was burst by the freezing of the water which it contained.

This expansion has a most important influence in the pulverization of soils. The water which exists through all their minute portions, by conversion to frost, crowds the particles asunder, and when thawing takes place, the whole mass is more completely mellowed than could possibly be effected by the most perfect instrument. This mellowing is, however, of only short duration, if the ground has not been well drained to prevent its becoming again packed hard by soaking with water.

But this is not the most important result from the expansion of water. Much of the existing order of nature and of civilized life depends upon this property; without it the great mass of our lakes and rivers would become converted into solid ice; for, as soon as the surface became covered, it would sink to the bottom, beyond the reach of the summer's sun, and successive portions being thus added, the great body of all large rivers and lakes would become permanently frozen. But instead of this disastrous consequence, the ice, by

resting upon the surface, forms an effectual screen from the cold winds to the water below.

SECTION III.

LATENT HEAT.

If a vessel of snow, which has been cooled down to several degrees below freezing by exposure to the severe cold of winter, be placed over a steady fire with a thermometer in the snow, the mercury will rise by the increasing heat of the snow until it reaches the freezing point. At this moment it will stop rising, and the snow will begin to melt; and although the heat is all the time passing rapidly into the snow, the thermometer will remain perfectly stationary till it is all converted to water. The heat that goes to melt the snow does not make it any hotter; in other words, it becomes *latent* (the Latin word for *hidden*), so as neither to affect the sensation of the hand or to raise the thermometer. Now it has been found that the time required to melt the snow is sufficient to heat the same quantity of water, placed over the same fire, up to 172 degrees, or 140 degrees above freezing; that is, 140 degrees have become latent, or hidden, in melting the snow.

This same amount of heat may be given out again by placing the vessel of water out of doors to freeze. A thermometer will show that the water is growing colder by the escape of the heat, till freezing commences. After this it still continues to pass off, but the water becomes no colder till all is frozen, as it was only the *latent* heat of the water that was escaping.

A simple and familiar experiment exhibits the same

principle. Place a frozen apple, which thaws a little below freezing, in a vessel of ice-cold water. The latent heat of the water immediately passes into the apple and thaws it, and in an hour or two it will be found like a fresh apple and entirely free from frost; but the latent heat having escaped from the water next the apple, a thick crust of ice is found to encase it.

The amount of latent heat may be shown in still another way. Mix a pound of snow at 32 degrees, or at freezing, with a pound of water at 172 degrees. All will be melted, but the two pounds of water thus formed will be as cold as the snow, showing that for melting it the 140 degrees in the hot water were all made latent.

ADVANTAGES OF LATENT HEAT.

If no heat became latent by the conversion of ice and snow to water, no *time* would, of course, be required for the process, and thawing would be *instantaneous.* On the approach of warm weather, or at the very moment that the temperature of the air rose above freezing, snow and ice would all dissolve to water, and terrific floods and inundations would be the immediate consequence.

LATENT HEAT OF STEAM.

A still larger amount of latent heat is required for the conversion of water into steam; for, again place the vessel of water with its thermometer on the fire, it will rise, as the heat of the water increases, to 212 degrees, and then commence boiling. During all this

time it will now remain stationary at 212, till the water is all boiled away. This is found to require nearly five times the period needed to heat from freezing to boiling; that is, nearly one thousand degrees of heat are made latent by the conversion of water into steam.

When the steam is condensed again to water, this heat is given out. Hence the use made of steam conveyed in pipes for heating buildings, and for boiling large vats or tubs of water, by setting free this large amount of latent heat which the fire has imparted to it.

GREEN AND DRY WOOD FOR FUEL.

A great loss is often sustained in burning green wood for fuel, from an ignorance of the vast amount of latent heat consumed to drive off the water the wood contains. When perfectly green, it loses about one third of its weight by thorough seasoning, which is equal to about 25 cubic feet in every compact cord, or 156 imperial gallons. Now all this water must be evaporated before the wood is burned. The heat thus made latent and lost, being five times as great as to heat the water to boiling, is equal to enough for boiling 780 imperial gallons in burning up every cord of green wood. The farmer, therefore, who burns 25 green cords in a winter, loses heat enough to boil more than fifteen thousand gallons of water, which would be saved if his wood had been previously well seasoned under shelter.

The loss in using green fuel is, however, sometimes overrated. It has been found by experiment that one pound of the best seasoned wood is sufficient to heat

27 lbs. of water from the freezing to the boiling point.* This will be equal to heating and evaporating four pounds of water by every pound of wood. The 25 cubic feet of water, therefore, in every cord of green wood, weighing about 1500 pounds, would require nearly 400 pounds of wood for its evaporation, or about one seventh or one eighth of a cord. Hence we may infer that seven cords of dry wood are about equal to eight cords of green. This imperfect estimate will apply only to the best hard wood, and will vary exceedingly with the different sorts of fuel; the more porous the wood becomes, the greater will be the necessity for thorough seasoning.

Superficial observation often leads to very erroneous conclusions. Seasoned wood will sometimes burn with great rapidity, and, producing an intense heat for a short time, will favor an over-estimate of its superiority. Green wood, on the other hand, kindles with difficulty, and burns slowly and for a long time; hence, where the draught of the chimney can not be controlled, it may be the most economical, because a less proportion of heat may be swept upward than by the more

* The following results show the heating power of several combustibles:

1 lb. of wood (seasoned, but still holding 20 per cent. of water) raised from 32° to 212°	27	lbs.	water.
1 lb. of alcohol	68	"	"
1 lb. of charcoal	78	"	"
1 lb. of oil or wax	90	"	"
1 lb. of hydrogen	216	"	"

It should be remembered that by ordinary modes of heating water, a very large proportion of the heat is wasted by passing up the chimney and into surrounding bodies, and the air.

violent draught produced from dry materials. Where the draught can be perfectly regulated, however, seasoned wood should be always used, both for convenience and comfort, and for economy.

Where wood is to be drawn to a distance, the preceding estimate shows that the conveyance of more than half a ton of water is avoided in every cord by seasoning.

CHAPTER II.

RADIATION OF HEAT.

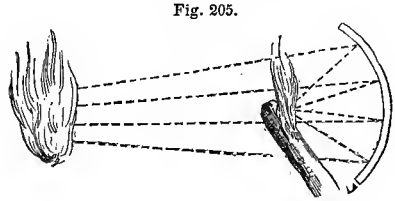
The passage of heat through conducting bodies has been already explained. There is another way in which it is transmitted, termed *radiation*, in which it is thrown off instantaneously in straight lines from hot bodies, in the same way that light is thrown off from a candle. A familiar instance is furnished by the common or open *fire-place*, before which the face may be roasted with the radiated heat, while the back is chilled with cold. A screen held in the hand will intercept this radiated heat, showing that it flies in right lines like the rays of light.

Radiated heat is reflected by a polished metallic surface, in the same way that light is reflected by a looking-glass. A plate of bright tin held near the fire will not for a long time become hot, the heat being reflected from it without entering and heating it. But if it be blackened with smoke, it will no longer reflect, but absorb the heat, and consequently will speedily become hot. This experiment may be easily tried by placing a new tin cup containing water over a charcoal fire, which yields no smoke. The heat will be reflected into the fire by the tin, and the water will scarcely become warm. But if a few pine shavings be thrown on this fire to smoke the surface of the tin, it will then absorb the heat rapidly, and soon begin to boil. This explains the reason that bread bakes more

slowly in a new tin dish, and that a polished andiron before a fire is long in becoming hot.

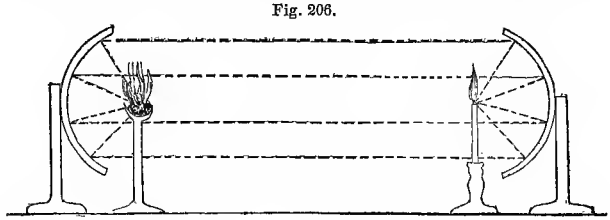
A concave burning-mirror, which throws the rays of heat to a focus or point, may be made of sheet-tin, by beating it out concave so as to fit a regularly curved gauge. If a foot in diameter, and carefully made, it will condense the rays of heat so powerfully at the focus, when held several feet from the fire, as to set fire to a pine stick or to flash gunpowder (*Fig.* 205).

Fig. 205.



The reflection of radiated heat may be beautifully exhibited by using two such concave tin mirrors. Place them on a long table several feet apart, and ascertain the focus of each by means of the light of a candle. Then place in the focus of one a red-hot iron ball, or a small chafing-dish of burning charcoal. In the focus of the other place the wick of a candle with a small shaving of phosphorus in it. The heat will be reflected, as shown by the dotted lines (*Fig.* 206),

Fig. 206.



and, setting fire to the phosphorus, will light the candle.

If a thermometer be placed in the focus of one mirror while the hot iron ball is in the other focus, it will rise rapidly; but if a lump of ice be substituted for the ball, the thermometer will immediately sink, and will continue to do so until several degrees lower than the surrounding air; because the thermometer radiates more heat to the mirrors, and then to the ice, than the ice returns.

DEW AND FROST.

All bodies are constantly radiating some heat, and if an equal amount is not returned by others, they grow colder, like the thermometer before the lump of ice. Hence the reason that on clear, frosty nights, objects at the surface of the earth become colder than the air that surrounds them. The heat is radiated into the clear space above without being returned; plants, stones, and the soil thus become cooled down below freezing, and, coming in contact with the moisture of the air, it condenses on them and forms *dew*, or freezes into *white frost.* Clouds return or prevent the passage of the heat that is radiated, which is the reason there are no night-frosts in cloudy weather. A very thin covering, by intercepting the radiated heat, will often prevent serious injury to tender plants. Even a sheet of thin muslin, stretched on pegs over garden vegetables, has afforded sufficient protection, when those around were destroyed.

FROST IN VALLEYS.

On hills, where the wind blows freely, it tends to restore to plants the heat lost by radiation, which is the reason that hills are not so liable to sharp frosts as still valleys. When the air is cooled it becomes heavier, and, rolling down the sides of valleys, forms a lake of cold air at the bottom; this adds to the liability of frosts in low places. The coldness is frequently still further increased by the dark and porous nature of the soil in low places radiating heat faster to the clear sky than the more compact upland soil.

A knowledge of these properties teaches us the importance of selecting elevated places for fruit-trees, and all crops liable to be cut off by frost; and it also explains the reason that the muck or peat of drained swamps is more subject to frosts than other land on the same level. Therefore, corn and other tender crops upon such porous soils must be of the earliest ripening kinds, so as to escape the frosts of spring by late planting, and those of autumn by early maturity.

REMARKABLE EFFECTS OF HEAT ON WATER.

The effects of heat and cold on water are of a very interesting character. Without its expansion in freezing, the soil would not be pulverized by the frost of winter, but would be found hard, compact, and difficult to cultivate in spring; without its expansion into steam, the cities which are now springing up, and the continents that are becoming peopled, through the influence of rail-ways, steam-ships, and steam manufactures, would mostly remain unbroken forests; without

the crystallization of water, the beautiful protection of plants by a mantle of snow, in northern regions, would give place to frozen sterility; without the conversion of heat to a latent state in melting, the deepest snows would disappear in a moment from the earth, and cause disastrous floods; without its conversion to a latent state in steam, the largest vessel of boiling water would instantly flash into vapor. All these facts show that an extraordinary wisdom and forethought planned these laws at the creation; and even what appears at first glance as an almost accidental exception in the contraction of bodies by cold, and which causes ice to float upon water, preventing the entire masses of rivers and lakes from becoming permanently frozen, furnishes one out of an innumerable array of proofs of creative design in fitting the earth for the comfort and sustenance of its inhabitants.

APPENDIX.

APPARATUS FOR EXPERIMENTS.

For the assistance of lecturers, teachers, and home students, the following list is given of cheap and simple apparatus and materials for performing most of the experiments described in this work. These experiments, although simple, exhibit principles of much practical importance. A few articles of a more costly character are given in a second list.

1. Inertia apparatus, p. 23. The concave post or stand is sufficient, the snapping being done by the finger, although a spring-snap performs the experiment more perfectly.

2. Weight with two hooks and fine thread, p. 23.

3. The inertia of falling bodies may be simply shown, and the pile-engine illustrated, by placing a large wooden peg or rod upright in a box of sand, and then dropping a weight upon its head at different heights, which will drive the rod into the sand more or less, according to the distance passed through by the falling weight.

4. A straw-cutter, so made that the fly-wheel can be easily taken off, will show in a very striking manner the efficacy of this regulator of force.

5. Two lead musket balls will exhibit the experiment in cohesion, p. 42. Balls or lead weights with hooks may be separated by suspending weights to show the amount of force required to draw them asunder. Metallic buttons or plates an inch in diameter, with hooks, will show the great strength needed to separate them when coated with grease, p. 42.

6. Capillary tubes of different sizes, two straight small panes of glass, and a vessel of water, highly colored with cochineal or other dye, to exhibit capillary attraction.

7. Glass tube, piece of bladder, and alcohol, for experiment described on p. 49.

8. The cylinder for rolling up the inclined plane, represented by

Fig. 18, p. 50, may be very easily made by using a round pastcboard box a few inches in diameter, and securing a piece of lead inside by loops made with a needle and thread. The object shown by *Fig.* 19 may be cut in one piece out of a pine shingle, the centre rod being lengthwise with the grain; the two extremities are shaved small, and wound with thick sheet-lead, and the whole then colored or painted a dark hue, to render the lead inconspicuous. The experiment with the penknives, p. 51, is very simple, care being taken to insert them low enough in the stick.

9. Irregular pieces of board, variously perforated with holes, and furnished with loops to hang on a pin, may be used to determine the centre of gravity, according to the principle explained by *Fig.* 21, p. 51.

10. Portions of plank and blocks of wood, with the centre of gravity determined as in the last experiment, may have a plumb-line (which may be a thread and small perforated coin) attached to this centre, and then be placed on differently inclined surfaces, to show their upsetting just as this line of direction falls without the base. Toy-wagons, bought at the toy-shops, may be variously loaded and used in experiments of this sort.

11. Experiments with the lever of the first kind may be easily performed by the use of a flat wooden bar, two or three feet in length, marked into inches, and placed on a small three-cornered block as a fulcrum. Weights, such as are used for scales, may be variously placed upon the lever. Levers of the second and third kind, which are *lifted* instead of borne down, may have a cord attached to the point where the power is to be applied, running up over a pulley or wheel, with a weight suspended to the other end.

12. An axle, furnished with wooden wheels with grooved edges, of different sizes, may be used to exhibit the principle of the wheel and axle, in connection with scale-weights that are furnished with hooks. The power of combined cog-wheels may be shown by a combination like that represented on p. 76, using weights for both cords.

13. Interesting experiments with the inclined plane, at different degrees of slope, by a contrivance similar to that represented by *Fig.* 87, p. 104, with the addition of a small wheel at the upper side for a cord to pass over. This cord is fastened at one end to a light toy-wagon, running up and down the plane, and at the other to a weight suspended perpendicularly just beyond the upper edge of the plane. The wagon is variously loaded with weights to counterpoise the suspended weight at different degrees of inclination.

14. A lecturer may quickly demonstrate before a class the small increase in the length of a road, in consequence of a considerable curve to one side of a straight line (as shown by *Fig.* 70), by using a cord for measuring, the diagram being marked on a board or the wall.

15. A round stick of wood, and a long, wedge-shaped slip of paper, easily show the principle of *Fig.* 75, p. 94.

16. A cog-wheel with endless screw and winch, *Fig.* 77, p. 95, exhibits distinctly the great power of the screw in this combination.

17. Pine sticks, two feet long, and one fourth to one half inch through, of different shapes and sizes, supported at each end, and with weights hung at the middle till they break, may be made to illustrate the principles described on p. 100, 102.

18. Some of the principles of draught may be shown, and especially those in relation to the different angles of inclination for hard and soft roads, by using a common spring-balance as a dynamometer, attached to a hand-wagon, and also to a sliding block of wood.

19. Bent glass tubes, with arms of different sizes to indicate the upward pressure of liquids, may be procured cheaply at glass-works. The experiment described by *Fig.* 154, p. 182, may be rendered easy and interesting by purchasing a large and perfectly-working *syringe*, and attaching to its nose, by means of sealing wax, a slender glass tube two or three feet long. Fill the syringe with water, leaving the tube empty; then, with the tube upright, drive the water up through it with the piston of the syringe, and the increased weight felt on the piston as the column of water rises will be very evident.

20. A hydrostatic bellows a foot in diameter, made by any good mechanic, will answer the purpose well, and exhibit an important principle.

21. Specific gravities may be shown before a class by a common balance and a fine cotton or silk thread.

22. A tin pail, with a hole half an inch or an inch in diameter at the bottom, will show the contracted stream which pours from it, p. 191. A short tin tube, with a slight flange at the upper end (quickly made by any tin-worker), fitted into this hole, will increase the discharge, as shown by *Figs.* 159, 160, and the difference in time for emptying the vessel may be measured by a stop-watch.

23. Archimedes' screw is readily made by winding a lead pipe round a wooden cylinder.

24. A glass syphon, filled with cochineal water, shows distinctly the theory of waves, by blowing with the mouth into one end.

25. Any vessel, filled with sand which has been heated over a fire, with rods of different substances, nearly of an equal size and length, and thrust with one end into the hot sand, in an inclined or nearly horizontal position, will exhibit the various conducting powers of these rods by melting pieces of wax or tallow placed on the ends most remote from the sand.

26. The expansion by heat may be demonstrated by fitting an iron rod to a hole in sheet iron; on heating the bar, it can not be made to enter. Or, if a hot iron ring be slipped on a tapering cold iron rod, it will contract on cooling so that the force of a man can not withdraw the rod.

27. The rising and descending currents in a vessel of heating water are easily rendered visible by throwing into a glass vessel, or flask, over a lamp, particles of sawdust from any hard green wood, whose specific gravity is about the same as that of water.

28. Instrument figured on p. 241, for showing the principle of the steam-engine.

29. Experiments in latent heat may be easily exhibited with the assistance of a common thermometer.

30. Tin mirrors for showing radiation, p. 254.

Second List, containing a few of the more costly pieces of apparatus for experiments as described in this treatise.

1. A good compound or solar microscope will exhibit the minute animalcules described under the head of *Divisibility*. The larger of these animalcules may be seen in old strong vinegar, and the smaller in a drop of water taken from a vessel in which a portion of raw potato has been soaked a few hours in a warm place. The same instrument will show the pores of wood mentioned under the head *Impenetrability*.

2. Atwood's machine, p. 39.

3. A good dynamometer for field experiments is of great value and importance.

4. An air-pump, with the several pieces of apparatus connected with it, shows, in an interesting and striking manner, several important principles.

HYDROSTATICS AND HYDRAULICS.

TABLE OF SPECIFIC GRAVITIES.

Metals.

Gold, pure	19.36	Iron	7.78
" standard	17.16	" cast	7.20
Mercury	13.58	Steel	7.82
Lead	11.35	Brass, common	7.82
Silver	10.50	Tin	7.29
Copper	8.82	Zinc	6.86

Stones and Earths.

Brick	1.90	Gypsum	1.87 to 2.17
Chalk	2.25 to 2.66	Limestone	2.38 to 3.17
Clay	1.93	Lime, quick	.80
Coal, anthracite, about	1.53	Marble	2.56 to 2.69
Coal, bituminous	1.27	Peat	.60 to 1.32
Charcoal	.44	Salt, common	2.13
Earth, loose, about	1.50	Sand	1.80
Flint	2.58	Slate	2.67
Granite, about	2.65		

Woods—dry.

Green wood often loses one third of its weight by seasoning, and sometimes more. The same kind varies in compactness with soil, growth, exposure, and age of the trees.

Apple	.68 to .79	Pine, yellow	.55 to .66
Ash, white	.72 to .84	Oak, English	.93 to 1.17
Beech	.72 to .85	" white	.85
Box	.91 to 1.32	" live	.94 to 1.12
Cherry	.71	Poplar, Lombardy	.40
Cork	.24	Pear	.66
Elm	.58 to .67	Plum	.78
Hickory	.84 to 1.00	Sassafras	.48
Maple	.65 to .75	Walnut	.67
Pine, white	.47 to .56	Willow	.58

Miscellaneous.

Beeswax	.96	Oil, whale	.92
Butter	.94	" turpentine	.87
Honey	1.45	Sea water	1.02
Lard	.94	Sugar	1.60
Milk	1.03	Tallow	.93
Oil, linseed	.94	Vinegar	1.01 to 1.08

Weights of a Cubic Foot of various Substances, from which the Bulk of a Load of one Ton may be easily calculated.

Cast Iron	450	pounds.
Water	62	"
White pine, seasoned, about	30	"
White oak, " "	52	"
Loose earth, about	95	"
Common soil, compact, about	124	"
Clay, about	135	"
Clay with stones, about	160	"
Brick, about	125	"

Bulk of a Ton of different Substances.

23 cubic feet of sand, 18 cubic feet of earth, or 17 cubic feet of clay, make a ton. 18 cubic feet of gravel or earth before digging, make 27 cubic feet when dug; or the bulk is increased as three to two. Therefore, in filling a drain two feet deep above the tile or stones, the earth should be heaped up a foot above the surface, to settle even with it, when the earth is shoveled loosely in.

DISCHARGE OF WATER THROUGH PIPES.

Table showing the amount of water discharged per minute through an orifice one inch in diameter; also through a tube one inch in diameter and two inches long, according to experiment. To ascertain the amount in gallons, divide the cubic inches by 231.

Height of head of Water.	Amount discharged through Orifice.	Amount discharged through Tube.
1 Paris foot*	2,722 cub. in.	3,539 cub. in.
2 "	3,846 "	5,002 "
3 "	4,710 "	6,126 "
4 "	5,436 "	7,070 "
5 "	6,075 "	7,900 "
6 "	6,654 "	8,654 "
7 "	7,183 "	9,340 "
8 "	7,672 "	9,975 "
9 "	8,135 "	10,579 "
10 "	8,574 "	11,151 "
11 "	8,990 "	11,693 "
12 "	9,384 "	12,205 "
13 "	9,764 "	12,699 "
14 "	10,130 "	13,177 "
15 "	10.472 "	13,620 "

VELOCITY OF WATER IN PIPES.

The following table shows the height of a head of water required to overcome the friction in horizontal pipes 100 feet long, and to produce a certain velocity, according to SMEATON:

Bore of Pipes.	6 *Inches.*	1 *foot.*	1½ *feet.*	2 *feet.*	3 *feet.*	4 *feet.*	5 *feet.*
in.	in.	in.	in.	ft. in.	ft. in.	ft. in.	ft. in.
½	4.5	16.7	35.1	4 9.7	10 1.0	17 10.0	28 0.2
¾	3.0	11.1	23.3	3 2.5	6 8.6	11 10.6	18 8.1
1	2.2	8.4	17.5	2 4.9	5 0.5	8 11.0	14 0.0
1¼	1.8	6.7	14.0	1 11.1	4 0.4	7 1.6	11 2.5
1½	1.5	5.6	11.7	1 7.2	3 4.3	5 11.3	9 4.1
1¾	1.3	4.8	10.0	1 4.5	2 10.6	5 1.1	8 0.1
2	1.1	4.2	8.7	1 2.4	2 6.2	4 5.5	7 0.0
2¼	1.0	3.7	7.8	1 0.8	2 9.9	3 11.6	6 2.7
2½	0.9	3.3	7.0	0 11.5	2 0.2	3 6.8	5 7.2
3	0.7	2.8	5.0	0 9.6	1 8.2	2 11.7	4 8.0
3½	0.6	2.4	5.0	0 8.2	1 5.3	2 6.6	4 0.0
4	0.6	2.1	4.4	0 7.2	1 3.1	2 2.7	3 6.0

Look for the velocity of the water per second in the pipe, in the upper line; and in the column beneath it, and opposite the given diam-

* A Paris foot is about 12 4-5 U. S. inches, and 15 Paris feet are about 16 U. S. feet.

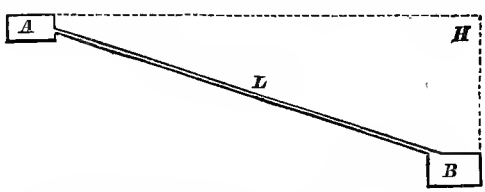
eter of the pipe, is the height of the column or head required to obtain the required velocity.

To find the quantity of water discharged each minute, multiply the velocity by 12, which will give the inches per second; then multiply this product by 60, which will give the inches per minute; then, to change these cylindrical inches into cubic inches, multiply by 4 and divide by 5.* Divide the cubic inches by 231, and the result will be gallons.

By comparing this table with the next preceding, we shall perceive that the water flows from three to four times as fast through the tube two inches long, as through a tube one hundred feet long, the diameter of the tube and the head of water being the same.

RULE FOR THE DISCHARGE OF WATER.

The following general formula, or rule applicable to different cases, has been furnished by a practical engineer. It may be useful in ascertaining the quantity required to fill the driving pipe of a water-ram, and for various other purposes occasionally occurring in practice.



Let A represent the fountain or reservoir from which water is to be conveyed to the trough B through the pipe L. Let N be the height of the surface of the water in the reservoir, above the place of discharge, and let D be the diameter of the tube in the smallest part. It is required to find the quantity Q which will be discharged in a second of time. The length and height being given in feet, and the diameter of the tube in inches, the formula, when the quantity is required in gallons, is as follows:

$$Q = 0.608 \sqrt{\left(D^5 \frac{H}{L}\right)}.$$

* This gives the cubic inches very nearly; but, to be more accurate, multiply by the decimal .7854, which represents the difference between the area of a square and of a circle.

In order to make the above formula more intelligible:

Let L = 80 rods or 1320 feet.
" H = 50 feet.
" D = 2 inches.
" Q = gallons.

Then $Q = 0.608\sqrt{(32 \times \frac{50}{1320})} = 0.67$; or, the same may be thus expressed in words.

Divide the height (50) by the length (1320); multiply the quotient by the fifth power of the diameter (fifth power of 2 = 32); extract the square root of the product, which, being multiplied by 0.608, will give (0.67) the number of gallons the tube will discharge in one second; which in this case is 40 gallons in one minute.

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